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ORIGINAL RESEARCH ARTICLE

SIZING ANALYSIS OF HYBRID ENERGY SUPPLY FOR BUILDINGS INTEGRATED WITH BATTERY STORAGE

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ABSTRACT

One of the limitations in the application of renewable energy sources is the intermittency and variability in its supply. This characteristic has attracted many researchers and stake-holders to focus on the application of different types of hybrid energy technologies with storage systems to improve in the efficiency of the supply and dispatch ability of the system. The application of hybrid energy technology to generate heat and electricity is very popular nowadays and sustainable in the supply of energy for on-grid and off-grid services. The sizing of the hybrid energy supply is paramount to saving energy and meeting the energy demand at all time. This research work involves an analysis for sizing hybrid energy supply integrated with battery storage to meet the energy demand for 3-bedroom, office, sports and school building. Merit modelling tool was applied for the demand and supply matching and analysis of the various chunks of technologies of PV, WT, CHP and generator were carried out based on the suitability to achieve the best matching. The results show that hybrid systems with output capacities of 2.96 MWh, 203.15 MWh, 1.38 MWh and 2.14 MWh were used to meet the energy demands of 3-bedroom, office, sports and school buildings. The office building energy sizing was achieved with a match rate of about 90% with no energy deficit. However, surplus energy of 34.2MWh was recorded. The 3-bedroom, sports and school energy sizing were achieved with less than 1MWh of energy surplus or deficit and a matching rate of about 60%. For future study, the performance of the identified energy technologies can be verified using an integrated building performance simulation tool to ascertain its feasibility.

1.0 Introduction

The demand for energy and its sustainability is one of the major challenges confronting the energy sector in the world. The energy demand is predicted to be enormous and requires sustainable measures for its supply. The entire world is experiencing continuous increase in population, modernization and industrial development and these have led to higher energy demand General use of available energy sources and the application of appropriate technology will enable demand for energy to be met. Over the past decades, most of the energy production were based on the combustion of fossil fuels accounting for more than 80% of the total energy generation worldwide (IEA, 2017). The continuous increase in the price of the fossil fuel is one of the major concerns that make the application of the energy unattractive nowadays. The awareness for the depleting characteristics of fossil fuel at long run has been stressed by many researchers and its applications are responsible for the release of harmful substances to the environment (Negi and Mathew, 2014; Krishna and Kumar, 2015; Raza *et al*., 2022). Many policies have been formulated around the world with a view of increasing the share of renewable energy and reduction in emissions as part of the response to the climate change (Mathiesen *et al*., 2011; Blazquez, *et al*., 2018; Raza *et al*., 2022) which has severe negative impacts to the environment. The drawbacks associated with the use of the conventional energy has push so many stake holders and researchers towards the utilization of an alternative energy sources to provide heat and power for homes and industrial applications. The continuous application of renewable energy technology to provide heat and electricity can serve as an effective solution leading to reducing the inter dependency on the conventional energy sources (Nguyen *et al*., 2019). The application of the renewable energy source for heat and power generation has been demonstrated by many researchers as the most sustainable energy source which has less negative effect on the health and nature (Negi and Mathew, 2014; Quaschning, 2016). One of the advantages of the renewable energy system (RES) is that the system can be developed as stand-alone or on-grid and can be located close to consumers. This decreases the transmission and transformation loses depending on the type of the RES applied. The RES is associated with high initial cost that leads to higher price of energy. However, the overall cost of the system greatly overweighs the increasing cost of fossil fuels, operation and maintenance cost and the cost of releasing harmful substances into the atmosphere.

The major problem that limits the use of the renewable energy sources is its variability and intermittency nature (Mathiesen *et al*., 2011; Yaqoot *et al*., 2016; Bahramara *et al*., 2016). Several efforts have been used to meet the energy demand utilizing the application of different types of hybrid renewable energy systems. For example, solar energy is obtainable in day-light, variation in wind speed also has great effect on the output of the system. Hybrid combination of these energy sources promises for a greater system performance and reliability towards overcoming the intermittency and variability character. The intermittency in the solar radiation and wind speed variation have been mitigated by the application of hybrid renewable energy systems integrated with storage facility to improve the efficiency of the system and the dispatch ability. Olatomiwa *et al*. (2016) discussed on how to overcome the variability and intermittency nature of the renewable energy sources by the integration of a hybrid renewable energy systems with energy storage systems (ESS). The ESS applied to hybrid energy technologies includes batteries, compressed air energy storage, flywheel, fuel cell, magnetic energy storage, superconductor, thermal energy storage systems etc. (Negi and Mathew, 2014; Zohuri, 2018).

Renewable energy sources such as solar, wind, biomass, tidal, fuel cells, geothermal etc. are usually combined to form a hybrid system that is more reliable and free from environmental pollution. Hybrid energy technology involved the combination of two or more renewable energy sources, or renewables and conventional energy along with ESS in order to guarantee the reliability in the energy supply (Elhadidy and Shahid, 2000; Mahesh and Sandhu, 2015; Zohuri, 2018) with an equipment that control the power (Nema *et al.,* 2009). The benefit for the use of a hybrid energy system (HES) is targeted towards its reliability of supply as the system combines two or more energy sources which is an added advantage for energy storage in the combined strength of the systems. The energy storage facility supplements for the output in case of a reduction in strength in one of the resources due to climatic variations to improve in the dispatch ability of the system. Stand-alone systems with one energy source are less adaptable to fluctuations in load. The fluctuation condition may lead to system collapse when it experiences a large variation in the load (Negi and Mathew, 2014). Most configurations of HES are commonly based on the solar and wind energy sources. Hybrid configurations may also consist of Biomass-Concentrated Solar Power (CSP), coal/gas-CSP, Photovoltaic (PV)-fuel cell, PV/geothermal, wind-biodiesel, wind-tidal systems etc. integrated with an ESS (Negi and Mathew, 2014; Zohuri, 2018). The HES with more than two energy sources generate greater electrical output and are more reliable. However, these types of HES are sometimes limited with the availability of the different energy sources at the same area and are usually associated with high capital, operation and maintenance cost. Figure 1 shows the schematic diagram of distributed energy generation. The hybrid energy output is supplemented by the storage systems that are all connected to the electrical control devices for grid and off-grid energy supply. The selection for any of the combinations of the HES strictly depend on many factors such as the weather condition of the area, energy demand, availability of space and building location (Yang *et al*., 2007).

The sizing of the energy systems plays an important role in the selection criteria. Analysis must be carried out in order to select for the optimum combination for a HES. The designs of the components and configurations of the HES can be optimized to make for flexibility in operation with a view in selection of the system configuration based on performance requirement and economy. For example, the sizing of the HES requires the best matching technologies that meet the requirement of building energy demand at all times. Optimal sizing of the HES can greatly promote penetration of the system and improve the technical and economic performance of the energy supply to buildings (Deshmukh and Deshmukh, 2008). In the present study, hybrid energy supply sizing analysis was conducted for building integrated with battery storage. The sizing approach is strategically based on the analysis of matching hybrid energy supply. This involved the matching of several chunks of technologies of hybrid energy with battery storage system to meet the energy demands of buildings. The battery storage was applied to mitigate the hybrid energy supply. The main importance of the battery storage system is to store excess energy for later use in the case of a variation in the supply of power or when no renewable energy source is recorded.

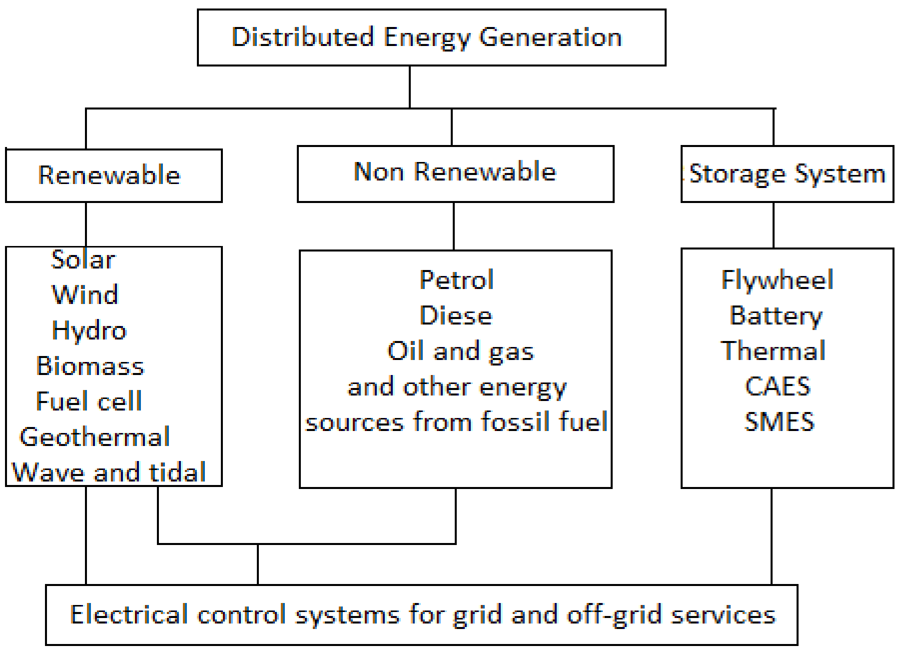

Figure 1: Schematic diagram for a hybrid distributed energy generation

2. Materials and Methods

The sizing of the HES is one of the major issues that are affecting the hybrid energy supply to meet building energy demand. Optimal sizing of the HES gives rise to a better performance of the system, energy and cost saving (Anoune *et al*., 2018a). Several methods of sizing hybrid systems have been studied by many researchers (Rouhani et al., 2013; Upadhyay and Sharma, 2014; Koubaaa *et al*., 2021). The deterministic and stochastic approach use the meteorological data for the yearly average monthly data and the data for the worst months of solar radiation and wind speed (Luna-Rubio *et al*., 2012; Anoune *et al*., 2018b). This sizing methodologies, usually lead to the oversizing of system components due to the uncertainty in the availability of solar radiation and wind speed either for both cases of the average monthly and worst month data (Luna-Rubio *et al*., 2012). Iterative sizing method is based on the total cost involving for example number of PV and wind turbine (WT) units. This is unlike the analytic method which utilise a computational method that describe the size of the HES as a function of its feasibility (Upadhyay and Sharma, 2014). A graphical construction method for sizing a stand-alone PV-wind hybrid system has been presented (Markvart, 1996). The sizing approach was based on meeting the energy demand in relation to the average solar radiation and wind speed required for the energy supply by the system. Clarke et al. (2013) presented a study on sizing hybrid energy schemes and the generation of a simulation input model for performance appraisal specifically for low energy communities. The study outlined the procedures for sizing of the HES and how to generate initial input models considering the capacity levels of each technology to achieve a successful demand and supply matching.

Most of the methodologies applied in sizing the HES are centred on the analysis of the various components and the overall configuration of the system, cost and performance approach. The present work involved application of the procedure outlined in the work of Clarke et al. (2013) where the sizing methodology is based on the analysis of hybrid energy supply schemes. Hybrid technologies of interest with different capacities are selected for example PV, wind turbine, generator, CHP systems chunked to meet energy demand of buildings. However, the present work put into practice, the procedure outlined for sizing the hybrid energy supply, to meet building's energy demand. Simulation was conducted using Merit software for the sizing analysis. This was achieved through matching of several chunks of technologies of hybrid energy supply with battery storage system. Data for energy demand; totality of energy requirement in a building in MWh, for different building types involving 3-bedroom dwelling, sports center, office and school were used in the analysis. The buildings were all located in Glasgow, UK on latitude 55.5 and longitude -4.15 with the average weather condition of the area applied. Most importantly, the wind speed and solar radiation at the particular period were used in the Merit tool for the PV and WT to obtain the power output.

In this analysis, hybrid system required for a particular building, for example sports center (PV, WT and battery) was chunked into t capacities of 100W, 500W, 30 kWe, and 50 kWe. Multiple batteries of capacities 50Ah@12V, 80Ah@12V and 120Ah@12V connected in either parallel or series were integrated to meet the energy demand for the various buildings. The distributed energy system is sized by using dual-mode inverter system that connects AC and DC buses to control the load requirement. A block diagram description is illustrated in Figure 2. Because of the intermittency in solar radiation and wind speed, battery systems are employed in connection to the inverter of the hybrid system to store electrical energy for later use.

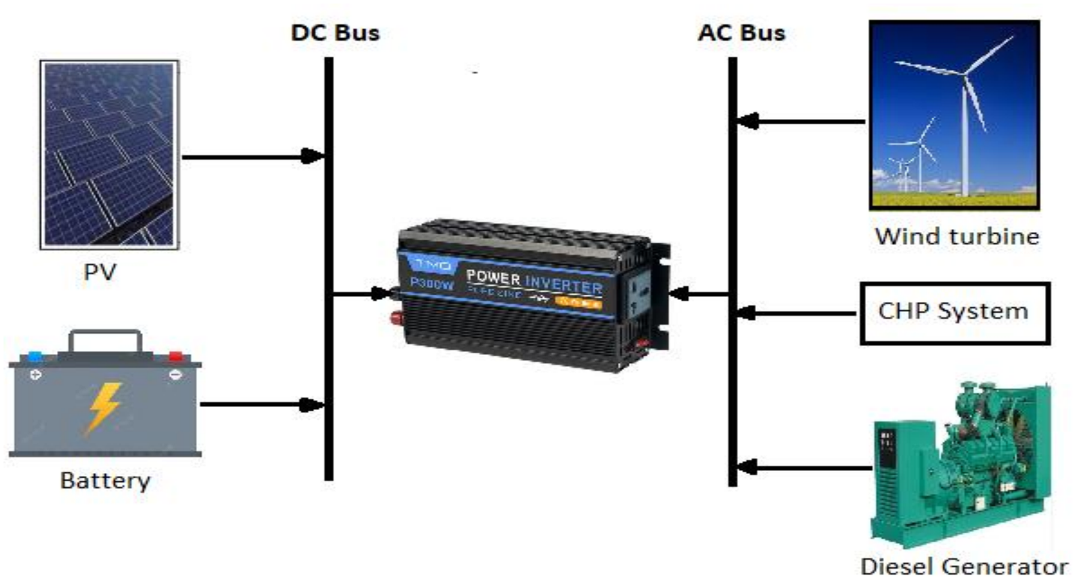

Figure 2: Block diagram of the distributed energy resources for hybrid system combination

The battery charge state is ascertained at different time when discharged to meet load requirement. Detailed analysis of battery state of charge for PV, WT and biomass hybrid system has been described (Sawle et al., 2018). The battery capacity is dependent on the load requirement during a particular period. The battery storage capacity (B_{SC}) is obtained using Equation 1 where D_{OD} is the battery allowable depth of discharge, E_L is the daily load energy of the battery, A_D is autonomy days that indicate the expected number of days for battery load supply, η_{iv} is inverter efficiency and η_B is the battery efficiency (Ismail *et al*., 2013).

$$B_{SC} = \frac{(E_L \times A_D)}{\eta_{iv} \times \eta_B \times D_{OD}} \tag{1}$$

In calculating the WT power output, several factors are considered. Factors such as the ambient temperature and terrain of the area, the altitude that defined the turbine position from the base level, season of the year and wind speed are important in determining the performance of the WT system. Wind gradient, which often defined the performance of the WT system, depends on these factors. The power output of the WT system was calculated using Equation 2 where P_{WT} is the power produced by the turbine system (kW), P_{RW} is the wind rated power (kW), V_R the nominal speed of the turbine system (m/s), V is the wind speed (m/s), v_{CI} is the cut in speed (m/s) and v_{CO} is the cut out speed (m/s) (Sawle et al., 2018).

$$P_{WT} = \begin{cases} 0 & V \leq V_{CI} \text{ or } V \geq V_{CO} \\ P_{RW} \left(\frac{V - V_{CI}}{V_R - V_{CI}}\right) & V_{CI} < V < v \\ P_{RW} & V_R \leq V \leq V_{CO} \end{cases} \tag{2}$$

The power output of PV system is explicitly dependent on the amount of solar radiation through the roof area defined by the number of panels of the PV system applied. The power generated by the PV system is directly proportional to the solar radiation. Other factors that affect the performance of the system includes angle of inclination, cell temperature, weather condition and geographical location. The power output of the PV panel was calculated at time t, by applying the Equation 3 where P_{PV} is the PV system peak power generation (kW), P_{RS}, is the rated power of the PV panel (kW), R is radiation factor, R_{CR}, is the certain radiation at 150 W/m^2 and R_{SRS} is the standard solar radiation at 1000 W/m^2 (Sawle et al., 2018; Jamshidi and Askarzadehj, 2019).

$$P_{PV} = \begin{cases} P_{RS} \left(\frac{R^2}{R_{SRS}\ R_{CR}}\right) & 0 \leq R < R_{CR} \\ P_{RS} \left(\frac{R}{R_{SRS}}\right) & R_{CR} \leq R < R_{SRS} \\ P_{RS} & R_{SRS} \leq R \end{cases} \tag{3}$$

In CHP system, the scale of power output is determined by the amount of fuel consumption of the system. This is in totally of the fuel used for the generation of electricity and the fuel used for auxiliary heating. The electrical output generation is obtained by multiplying the power output of the CHP system with number of dark hours (Pearce, 2009). The main advantage of the CHP system is to provide a complete backup to the PV or WT output in order to maintain a constant load, during an intermittent condition of solar radiation or wind speed. The CHP system was designed to correlate between demand and supply load in order to maximize the CHP fuel efficiency and improve system maintenance (Nosrat and Pearce, 2011).

The hybrid system is designed to use a variable speed diesel generator in order to meet the electrical load requirement at various scales of power output. This is so important in that the diesel generator can provide load at different power output in case of deficit in the power supply by other energy systems. The main function of the generator is to balance the hybrid power source in case when the battery is depleted to its allowable depth. The generator is conditioned to operate also as a back up to the intermittent nature in the supply load of PV and WT systems. The generator rated power is proportional to the system fuel consumption hence the scale of the actual power output of the system can be determined (Jamshidi and Askarzadeh, 2019).

3. Results and Discussion

Figures 3-6 show the power demand and supply profiles of the 3-bedroom, sports, Office and school buildings in Glasgow. Several chunks of hybrid technologies were analysed using Merit software for demand and supply matching. Hybrid capacities of PV, WT, CHP and generator systems with consideration to the various building requirement were applied with battery storage for the analysis. The surplus energy need to be stored by an efficient storage system in order to meet the energy demand. The results for the hybrid energy sizing analysis of the various building types were obtained from the simulation conducted using the Merit tool. The results obtained are presented in Table 1.

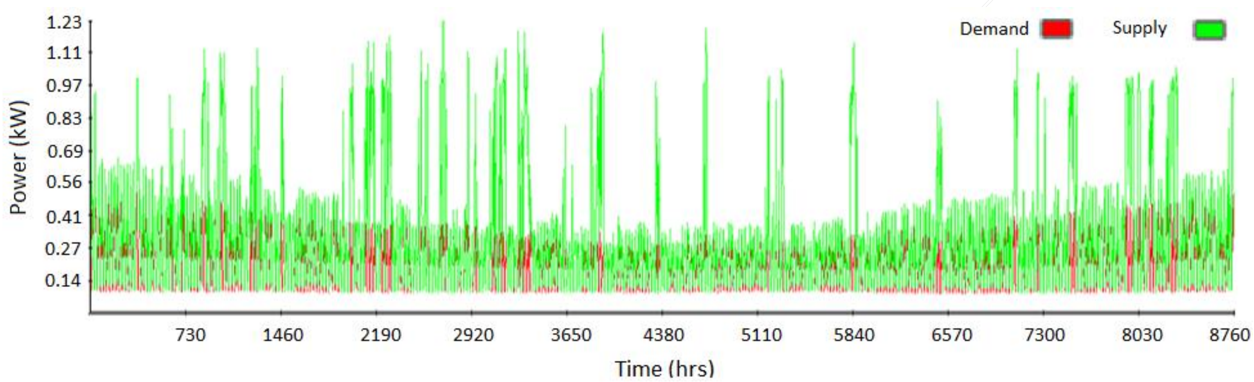

Figure 3: Power demand and supply matching profiles for 3-bedroom flat building

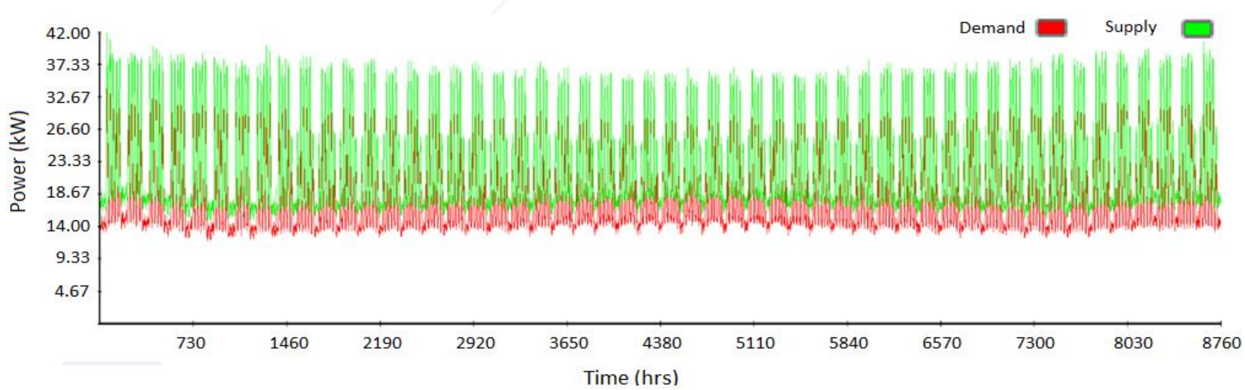

Figure 4: Power demand and supply matching profiles for Office building

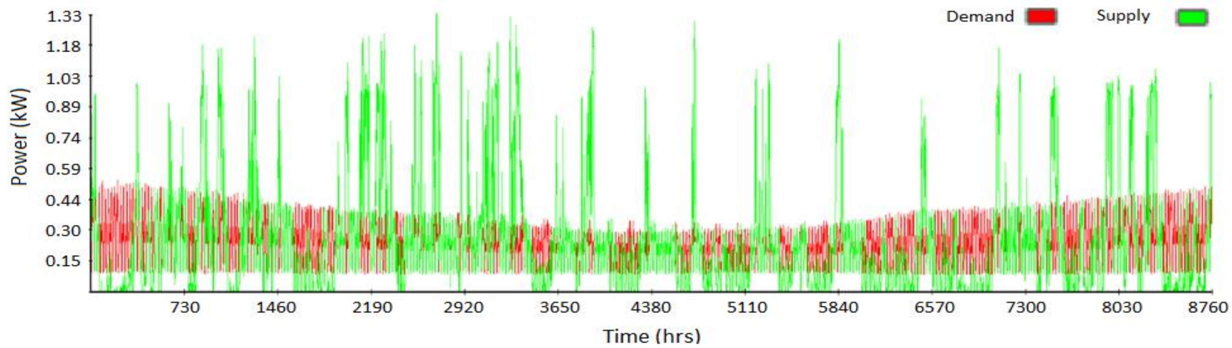

Figure 5: Power demand and supply matching profiles for sports building

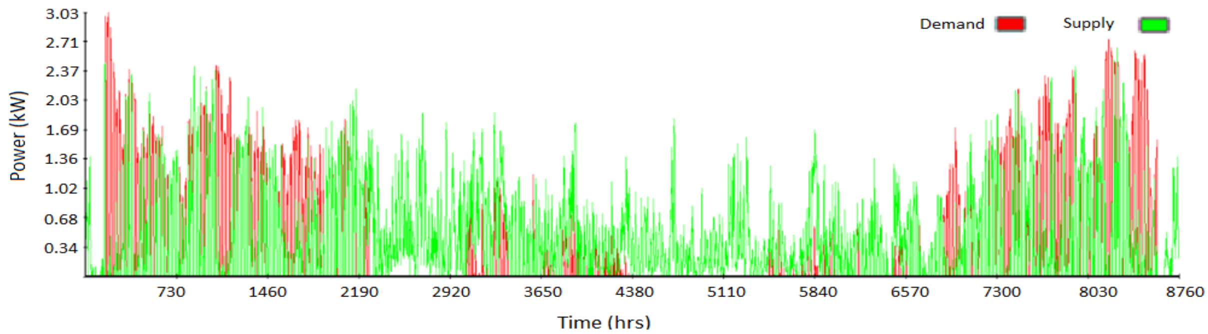

Figure 6: Power demand and supply matching profiles for school building

Table 1: Analysis of the buildings' energy demand and hybrid energy supply technologies

Building Types	Hybrid Combinations	Match Rate (%)	Correlation Coefficient	Total Demand (MWh)	Total Supply (MWh)	Energy Surplus (MWh)	Energy Deficit (MWh)
3-Bed	PV, WT, Generator and Battery	66.66	0.48	2.11	2.96	0.851	0.0005
Office	PV, WT, CHP and Battery	89.61	1.00	164.92	203.15	38.220	0
Sports	PV, WT and Battery	55.85	0.35	0.82	1.38	0.545	0.014
School	PV, WT and Battery	57.79	0.22	2.11	2.14	0.666	0.647

The hybrid systems of 3-bedroom, office, sports and school supplied energy of 2.96 MWh, 203.15 MWh, 1.38 MWh and 2.14 MWh respectively to meet the energy demands of the buildings. It can be observed from Table 1 that the hybrid supply for the 3-bedroom, office and sports buildings have sufficiently met the buildings energy demand with almost no deficit in the demand side. However, the office building recorded unusable energy supply of 38.22 MWh. This indicated that the hybrid energy supply for the office building was not well sized due to the surplus energy. The surplus energy is accounted when energy is not used or during period of high wind speed and solar radiation. The hybrid system capital and operation cost should be higher for the office and 3-bedroom buildings, due to the use of fossil fuel for the auxiliary energy generation and the cost of the emission of harmful substance into the environment. The analysis for the office sizing would have to be considered first before the 3-bedroom flat with a view of eliminating the auxiliary application utilising high cost of fossil fuel. This is in contrast to the school building that have the same energy demand as in the case of the 3-bedroom flat. However, their hybrid energy supply capacities are different. Emphasis should be given to the sizing of the energy supply schemes, in their capacities for the chunks of the PV, WT and battery storage systems in order to achieve the best match.

4. Conclusion

In this paper, hybrid energy supply sizing analysis was conducted using Merit modeling tool for demand and supply matching through chunks of capacities of PV, wind, CHP and generator integrated with a battery storage to meet the energy demands of 3-bedroom, office, sports and school buildings. The results showed that excess energy was recorded with higher percentage of matching rate for the office compared to the other buildings. However, no energy deficit was recorded in the 3-bedroom, office and sports buildings. The surplus energy recorded in the hybrid supply for the school building can balance up the deficit energy, when an efficient battery storage system is employed. The result analysis indicated that the sizing of the hybrid energy supply for the 3-bedroom, sports and school buildings was successfully achieved. However, there is the need to resize the hybrid energy supply for the office building, in order to avoid excess energy supply to the building.

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