Is it a possibility to achieve energy plus prefabricated building worldwide?

Ammar Alkhalidi¹,*, Abeer Abuothman², Abdallah AlDweik¹ and Al-Hamza Al-Bazaz¹

¹Energy Engineering Department, German Jordanian University, Amman, Jordan ²Civil and Environmental Engineering Department, German Jordanian University, Amman, Jordan

Abstract

Prefabricated buildings constructed to be used in a specific region cannot be assumed to work unconditionally in different climates around the world. It is important to develop passive house solutions for each location, suitable for the actual climate and geographic conditions. Shelters could be used in different applications such as refugee housing or telecommunication stations. Photovoltaic energy could cover the electricity consumption of these shelters. Shelters for different applications should be usable in all weather conditions, and because of that different climate zones were chosen. A full study about three climate zones was done to study the different factors that play a significant role in choosing the location of the shelter. In this study, prefabricated housing was designed to ensure thermal comfort by doing structure design changes and using solar energy as an energy source. Three different locations have been chosen to be able to perform the best structure and components design for every location, taking into consideration the assumptions taken in each place. The total photovoltaic system was designed with a capacity of hot, moderate and cold climate zones with 2.0, 1.8 and 3.45 kWp, respectively, along with energy plus the production of 38% in the hot, 47% in the moderate and 28% in the cold climate.

Keywords: energy plus; sustainable shelter; prefabricated building; thermal comfort;

*Corresponding author: ammar.alkhalidi@gju.edu.jo

Received 25 April 2020; revised 2 July 2020; editorial decision 15 July 2020; accepted 15 July 2020

1 INTRODUCTION

Prefabricated housings (PHs) are being more commonly used lately around the world due to the wars and natural disasters. Wars and natural disasters affecting billions of people, leaving them homeless, resulting in higher needs of refugee camps [1]. Along with that the developed and competitive telecommunications sector is focusing on serving reliable networks. Those networks are proposed to cover all areas, including remote rural areas, increasing the needs of well-designed service shelters [2].

Designing environmentally friendly shelters can participate in adapting to grand environmental challenges. Air pollution is reduced by reducing the amount of emitted harmful contaminants to the atmosphere. This could be done by replacing the conventional diesel generators with sustainable renewable energy source to power these shelters. Solar energy will be the one that will be used in this study design. Energy plus buildings is a new generation of houses where it produces more energy than it needs for lighting, heating and other energy-consuming facilities within it, using renewable energy technologies.

Solar energy has been used economically for many years as an energy source for building all over the world. This energy will ensure less environmental impact and fewer maintenance costs. A. Atmaca and N. Atmaca [1] studied the life cycle energy and cost of PH and container temporary housing (CH) in Turkey. Results showed that PH could save around the quarter of both cost and energy. Pons and Wadel [3] instigated the environmental impact of the prefabricated school building in California. Authors found that using industrialized technologies (steel, concrete structure and timber) in the structure of these PH can significantly reduce waste generation and resources consumption.

Ghafoor and Munir [4] designed a small off-grid photovoltaic (PV) system for a household. Authors believed that it is worthwhile to determine the proper design for the shelter. Proper design should satisfy the feasibility, viability, financing indicators and risk factors involved in the implementation of off-grid PV electrification system to enhance the acceptance rate of this technology.
Regarding thermal comfort, Saleh and Gadi [5] concluded that thermal sensation vote (TSV) in shelters with concrete block walls is lower than TSV in shelters with sand block walls. The same conclusion was in both summer and winter. The previous conclusion was in Palestine in the Middle East. While Yang et al. [6] figured out that solar radiation had the most significant effect on human thermal sensation in outdoor spaces in Singapore. In India Chandel and Sakar [7] proved that good design features for a passive solar building, include: fenestration and external shading design. Good design include fenestration and external shading design, modification of floor plans, creating cross-ventilation and providing solar air-heating panels that can participate effectively in maintaining indoor thermal comfort and minimizing the annual energy consumption.

Karthigeyan et al. [8] carried out a brief study in energy-efficient cooling techniques for telecom tower shelters. Results showed that the cooling system of these shelters in India is the most energy-consuming. Authors investigated the replacement of the conventional air conditioning unit with a more efficient one. Results showed that low carbon footprint cooling technologies, such as free cooling unit, thermosiphon, wind chimney and combination of phase-changing materials and geothermal cooling system, will be more efficient in different climate areas.

In regards of the energy-efficient buildings, Pacheco et al. [9] made a review about energy-efficient buildings. Authors focused on heating and cooling energy consumption in residential buildings. This was done by studying the influence of a number of parameters on energy demand such as passive heating and cooling, shading, glazing and building shape and orientation and suggested the optimum design options. Alkhalidi and Hatuqay [10] investigated and designed low-cost and energy-efficient residential units using printable walls. Authors investigated different wall configurations and materials to reduce the U-values taking climate zone regulations into consideration.

Alkhalidi et al. [11] had investigated the effect of glass properties by using variable glass to wall ratios on the heating and cooling loads in 4–20 story buildings in Amman, Jordan. Results showed a minimum impact of glass properties when the ratio was 20 percentile and highest effect when the ratio was 100 percentile. Alkhalidi also worked with Aljolani to ensure that green buildings can provide benefits to residential areas in Jordan. Authors investigated the designing and approach using eQuest simulation tool to improve the water and energy efficiency of mid-rise buildings. This work achieved savings in water, electricity and diesel along with achieving 44 points in the Leadership in Energy and Environmental Design green building rating system [12].

Kazanci et al. studied the sustainable heating, cooling and ventilation of a plus-energy house via photovoltaic/thermal panels. Authors found that energy saving for cooling requirements can reach up to 30% when using a combination of embedded pipes and phase change material (PCM) and the photovoltaic thermal panels can enable the house to act as plus energy house with solar fraction up to 63% and 31% in Madrid and Copenhagen, respectively [13].

Alkhalidi et al. worked on designing and selection of the location for a sustainable city in Jordan. This city is powered by renewable energy (Smart Grid), which was designed to house 50,000 inhabitants. The total area is ~11 128 km² of the city, including areas to be used for renewable energy, agricultural use, housing and waste treatment and industrials zones. Energy generation was proposed and studied by two scenarios the first is parabolic trough with thermal energy storage, the second scenarios is use of a hybrid PV and wind system [14].

Based on literature review present in this section, authors found that the energy plus prefabricated building was not investigated. This paper will study the design of energy plus prefabricated shelters powered with solar energy using photovoltaic panels in three different climate zones. The selected zones were as follows: hot as in Sahara desert; moderate as in Madaba, Jordan; and cold as in Stockholm, Sweden. These different climates were chosen to study the performance of the designed prefabricated building and the plus energy that can be produced in each, along with choosing the appropriate quantity and quality of PV cells for each climate zone by using weather data for each zone and simulation software to maintain thermal comfort and provide electrical power needs.

2 METHODOLOGY

The proposed shelter must provide a good life condition inside for a human being such as thermal comfort during the whole year and the electrical energy that can be used to operate some equipment inside. Factors that affect conditions inside the shelter can change the system. These factors include solar irradiation values, annual ambient air temperature values, set-up temperatures for HVAC system inside, the geometry and orientation of the shelter and other parameters. All of these parameters are discussed below in order to control the size and the configuration of the optimum system that should be installed.

2.1 Site description

Three different climate zones (hot, moderate and cold) were chosen to make sure that shelters could withstand any weather condition. For hot climate zone, Sahara Desert was chosen. Sahara has a mean temperature of 30°C and an average summer temperature of 40°C. The following coordinates will be studied: 23.4162° N, 25.6628° E. For cold climate zone, Stockholm, Sweden, with a latitude of 59° 20’ 4.5276” N and a longitude 18° 3’ 47.6640” E was selected. Stockholm has an average minimum temperature of -4°C and an average maximum temperature in summer of 20°C [15]. For moderate climate zone, Madaba, Jordan, with a latitude of 31.7769° N and a longitude of 35.804° E was selected with an average minimum temperature of 13°C and an average maximum temperature in summer of 33°C [15].

All the chosen cites was as near as possible to a weather station or at the same location. In addition, there must be more than one weather station close to the chosen location. SolarGIS® [16] and Meteonorm® [17] will be used as the main sources for weather data.
Table 1. Average yearly sun rays entering shelter with fixed space above windows.

| Overhang length | 0.1 | 0.25 | 0.3 | 0.35 | 0.4 | 0.45 |
|-----------------|-----|------|-----|------|-----|------|
| Avg. sun all in % |     |      |     |      |     |      |
| January         | 99.73% | 96.55% | 92.36% | 87.73% | 83.00% | 78.36% |
| February        | 96.18% | 90.18% | 84.09% | 77.55% | 70.82% | 63.91% |
| March           | 81.36% | 70.45% | 59.64% | 48.73% | 37.91% | 27.00% |
| April           | 22.33% | 8.11%  | 0.00% | 0.00% | 0.00% | 0.00% |
| May             | 0.00%  | 0.00%  | 0.00% | 0.00% | 0.00% | 0.00% |
| June            | 0.00%  | 0.00%  | 0.00% | 0.00% | 0.00% | 0.00% |
| July            | 0.00%  | 0.00%  | 0.00% | 0.00% | 0.00% | 0.00% |
| August          | 0.45%  | 0.00%  | 0.00% | 0.00% | 0.00% | 0.00% |
| September       | 57.55% | 40.91% | 27.73% | 15.18% | 4.45% | 0.00% |
| October         | 92.27% | 85.00% | 77.09% | 69.00% | 61.09% | 53.18% |
| November        | 99.00% | 94.91% | 90.18% | 85.18% | 80.09% | 74.73% |
| December        | 100.00% | 97.45% | 93.82% | 89.55% | 85.18% | 80.82% |

Table 2. Average yearly sun rays entering shelter with fixed overhang length.

| Overhang Spacing length | 0.05 | 0.15 | 0.25 | 0.35 | 0.45 | 0.55 |
|-------------------------|-----|------|-----|------|-----|------|
| Avg. sun all in %       |     |      |     |      |     |      |
| January                 | 63.55% | 73.55% | 83.00% | 91.18% | 97.36% | 100.00% |
| February                | 50.82% | 60.82% | 70.82% | 80.36% | 88.55% | 95.55% |
| March                   | 17.91% | 27.91% | 37.91% | 47.91% | 57.91% | 67.91% |
| April                   | 0.00%  | 0.00%  | 0.00% | 0.00% | 0.00% | 0.00% |
| May                     | 0.00%  | 0.00%  | 0.00% | 0.00% | 0.00% | 0.00% |
| June                    | 0.00%  | 0.00%  | 0.00% | 0.00% | 0.00% | 0.00% |
| July                    | 0.00%  | 0.00%  | 0.00% | 0.00% | 0.00% | 0.00% |
| August                  | 0.00%  | 0.00%  | 0.00% | 0.00% | 0.00% | 0.00% |
| September               | 41.09% | 51.09% | 61.09% | 71.09% | 80.64% | 88.82% |
| October                 | 60.27% | 70.27% | 80.09% | 88.27% | 95.36% | 99.91% |
| November                | 66.09% | 76.09% | 85.18% | 93.00% | 98.64% | 100.00% |

2.2 Structure design

Having a well-designed shelter and construction materials can participate greatly in decreasing energy losses and increasing the energy efficiency of the shelter. Below is the optimization of each main design component (overhang, shelter interior construction and building materials).

2.2.1 Overhang analysis

Overhang design could reduce heating and cooling loads. Overhang allows winter sun rays entering the shelter but it blocks summer sun rays. By using overhang, less energy would be required to have thermal comfort for shelter. Different parameters contribute to overhang design such as location, window height, the spacing between window and roof and the orientation of the roof angle and the length of the overhang itself [18].

Here in the three climate zones, the windows will be facing south to achieve maximal advantage from passive solar gains along with pitched roof, oriented to the south with 21.6° and a 1-meter window height. Therefore, the optimization method should include only window–roof spacing and overhang length for each climate zone. This will be decided by finding out the maximum percentage of solar radiation. Detailed optimization tables will be shown for the hot climate zone and the same was made for the other two zones.

Hot climatic zone: Location: Sahara Desert, New Valley Governorate, Egypt. Latitude: 23°24′58.3″ N; Longitude: 25°39′46.1″E

Climate type in this part of the world according to Köppen is BWh, which means hot desert climate [19]. By recognizing the monthly maximum temperatures, it was necessary to stop window solar irradiation from April to September. Catching the maximum amount of sun from October to March is very important during winter for heating. Then it can be concluded from Tables 1 and 2 that optimum overhang length is 0.4 m and window to roof spacing is 0.35 m.

• Normal climate zone: Location: Jordan, GJU Campus, Madaba Governorate Jordan. Latitude: 31°46′36.4″ N; Longitude: 35°48′09.0″E

Climate type in this part of the world according to Köppen is BSh, which means steppe hot arid climate [19]. By recognizing the monthly maximum temperatures, the time interval of weather...
change from summer to winter (and verse visa) is quite longer than the Sahara desert. Because of that, blocking sun irradiation is summer can be done gradually. Regarding this climate zone, the change is only in overhang length. Then it can be concluded from Tables 3 and 4 that the optimum overhang length is 0.5 m and window to roof spacing is 0.35 m.

- **Cold climate zone:** Location: Stockholm. Latitude: 59° 20’ 4.5276’’ N; Longitude: 18° 3’ 47.6640’’ E

  Climate type in this part of the world according to Köppen classification is Dfc, which means snow, fully humid and cool summer climate. By recognizing the monthly maximum temperatures, it is not necessary to put an overhang from the first place. However the main principle of the overhang is to minimize rainfalls on the walls as much as possible to decrease the heat convection coefficient, and that will result in better heat gains annually. Then it can be concluded from Tables 1 and 2 that the optimum overhang length is 0.05 m and Window to roof spacing is 0.55 m [19].

### 2.2.2 Shelter construction and materials

The shelter dimensions are 6m*3m that makes the shelter area of 18 Square meter. The shelter will consist of three south windows, a window and a door north-oriented and a small bathroom window. The occupied area split to a living-bed room and a partition used as a bathroom as shown in Figure 1 and 2 below:

For the materials of construction, different characteristics need to be taken into consideration. For example, the material used in the shelter should be strong and hard with low thermal conductivity, fire and waterproof and lightweight. These characteristics can be achieved by applying three layers of composite planes with the main material is polyurethane foam due to its low conductivity (0.0295 W/m.°C) [21].

Three types of walls will be used one for the walls and one for the ceiling. The first one for the walls consists of three layers and their thicknesses are as follows: 3 mm, decorative wood board; 47 mm, polyurethane foam; 1 mm, galvanized steel frame). Type two is for the ceiling, and it consists of a 47-mm polyurethane foam between two 3-mm decorative woods. Type three is for toilet partition, the same thickness of foam with two sides of preprinted slightly corrugated steel sheets, all of that framed with galvanized steel frame. Different types will be combined with H Joint (Square Edge Joint) and Lap Joint.

### 2.3 Electrical load estimation

Electrical loads are used in shelters for different applications (lamps, TV, water cooler, laptop, printer, motion sensor, security camera, water pump, refrigerator). To ensure energy-saving, LED lamps were used in rooms, which can participate in saving 25% of energy, motion sensor lamp in the corridor to reduce the number of usage hours. Detailed energy consumption is summarized in Table 4 below:

According to Table 8, it can be seen that 102.7 kWh is the monthly needed energy to support all equipment used in the shelter.
Is it a possibility to achieve energy plus prefabricated building worldwide?

2.3.1 Heating and cooling demand

Heating and cooling demands in parallel with thermal comfort requirements will be estimated using the Design Builder® software. Listed in Table 5 are the common parameters that were used to estimate the demand in the three climate zones.

The parameter mentioned in Table 5 were used to run the design builder® software, results for each climatic zone are listed in Table 6.

Figure 3 shows a visualization of temperature distribution in Stockholm. Results are based on thermal comfort values achieved since the template used is the same concerning setup temperatures.

2.4 Photovoltaic design and simulation

An off-grid system will be considered in this study. Depending on location, shelter’s energy consumption may change so that the system capacity may be different due to different weather data.

Table 4. Energy consumption in shelter.

| Equipment in use                  | No. equipment | Total wattage (W) | Daily use (h) | Daily energy (kWh/day) | Monthly energy (kWh/month) |
|-----------------------------------|---------------|------------------|---------------|------------------------|---------------------------|
| Lighting                          |               |                  |               |                        |                           |
| A19—E26                           | 2             | 18               | 5             | 0.09                   | 2.7                       |
| Philips T8                         | 4             | 68               | 10            | 0.68                   | 20.4                      |
| Motion sensor stick-up lamp        | 2             | 14               | 3             | 0.042                  | 1.26                      |
| Motion sensor lights, security lights | 2         | 100              | 4             | 0.4                    | 12                        |
| TV                                | 1             | 47               | 7             | 0.329                  | 9.87                      |
| Refrigerator                      | 1             | 100              | 5             | 0.5                    | 15                        |
| Security camera system             | 1             | 25               | 24            | 0.6                    | 18                        |
| Printer                           | 1             | 27               | 0.5           | 0.0135                 | 0.405                     |
| Laptop                            | 1             | 45               | 6             | 0.27                   | 8.1                       |
| Water cooler                      | 1             | 50               | 4             | 0.2                    | 6                         |
| Water pump                        | 1             | 800              | 1             | 0.8                    | 24                        |
| Sum of monthly energy use in kWh  |               |                  |               |                        |                           |
|                                  |               |                  |               | 102.7                  |                           |

Table 5. Shelter design and dimensions.

| Parameter made                  | Values or comments                                      |
|---------------------------------|---------------------------------------------------------|
| The geometry of the occupied area| Height: 2.88 m; width: 3 m; length: 6 m                   |
| Overall U-value of the shelter  | 0.510 W/m².K                                           |
| Type of refrigeration system    | Split unit                                              |
| COP                             | 2.94                                                   |
| EER                             | 10.1                                                   |
| Refrigeration system using profile| 8 hours a day depending on setup T                 |
| Refrigeration system setup temperatures| Maximum feeding temperature is 28°C; minimum feeding temperature is 18°C |
| Wall-to-window percentage       | 20%                                                     |
Table 6. Monthly and annual heating and cooling demands for each climate zone.

| Climate Zone | Maximum monthly average cooling demand | Maximum monthly average heating demand | Annual heating and cooling demand |
|--------------|----------------------------------------|----------------------------------------|---------------------------------|
| Stockholm    | 1.2 kWh/month                           | 240.2 kWh/month                        | 1301 kWh/year                   |
| Madaba       | 79.6 kWh/month                          | 88.5 kWh/month                         | 677.8 kWh/year                  |
| Sahara       | 1.4 kWh/month                           | 170.6 kWh/month                        | 1272 kWh/year                   |

The photovoltaic off-grid system includes solar panels, charge controller, batteries and inverter. Each component has a specific operating temperature range that can operate in different climate zones. Table 7 is a summary of all the PV off-grid system design components for each climate zone with the brand name and number of each component.

2.4.1 Energy data analysis
After designing the above components, the following energy data is calculated and summarized in Table 8:

3 RESULTS AND DISCUSSION

Depending on the cooling and heating demand that was estimated by Design Builder®, Figure 4 shows a graph comparing cooling and heating demand in peak days for the three climate zones:

It can be seen from the graph that each location will encounter different difficulties to fulfill HVAC energy demand. Sahara has a peak day electricity of 4.5 kWh/day for cooling and 0.66 kWh/day for heating. Madaba has a peak day electricity of 3.5 kWh/day for heating and 2.66 kWh/day for cooling. However, for Stockholm it is much simpler to recognize the main HVAC demand source that is heating with ~8.5 kWh/day.

To study the nature of each location, the annual solar irradiation was found to be 2338 kWh/m².year in Sahara, 2213 kWh/m².year in Madaba and 975 kWh/m².year in Stockholm. The previous data shows the challenges for Stockholm, which is the low global irradiation value of 975 kWh/m².year. Compared with Sahara and Madaba, Stockholm location has a big weak point for installing a PV system in addition to high heating demand in Stockholm, which makes maintaining heating demand only by the PV system impossible, especially that the available roof area is enough only for 12 PV module as a maximum number. Due to these difficulties, using a backup generator will be the optimum solution for this location.

3.1 System overview
Table 9 shows the load consumption, annual global irradiation and system capacity of each climate zone. Stockholm has higher load consumption due to the high heating demand needed to have thermal comfort. This could be attributed to the weather all over the year, so it also has a higher PV system capacity. Low irradiance leads to a decree in the system power generation as solar panels need high solar irradiance to generate more power. Based on that a larger system in Stockholm is needed to cover consumption load.

Normally, most days of the year will have a daily consumption lower than the peak days, and here the ‘plus energy’ comes. It is simply the actual consumption of any day of the year subtracted from peak day consumption estimation. This will make the amount of additional energy that can be stored or used in other applications outside the shelter (energy plus).

3.2 Energy plus analysis
The plus energy generated in each location will be shown in the analysis below by a graph for each climate zone.

Figure 3. CFD analysis over the shelter in all locations.
Is it a possibility to achieve energy plus prefabricated building worldwide?

Table 7. Off-grid system components.

| Off-grid system components | PV modules | Solar inverter | Battery inverter | Storage battery | Backup generator |
|----------------------------|------------|----------------|------------------|-----------------|-----------------|
| Sahara                     | JurraWatt 250 DESERT | SMA SUNNY BOY 1.5 | Sunny Island 3.0 M | TESV LT STORAGE battery 3.0 | - |
| Madaba                     | Canadian Solar 300MS | SMA SUNNY BOY 1.5 | Sunny Island 3.0 M | TESV LT STORAGE battery 2.0 | - |
| Stockholm                  | Canadian Solar 345 M | SMA SUNNY BOY 3.0 | Sunny Island 3.0 M | TESV LT STORAGE battery 5.0 | Genest |
| No. of components          | 8          | 1              | 3                | 1               | 1               |
| No. of components          | 6          | 1              | 3                | 1               | 1               |
| No. of components          | 10         | 1              | 3                | 1               | 1               |

Table 8. Off-grid system components.

| Energy consumption (kWh) | Energy production (kWh) | Energy directly consumed (kWh) | Energy stored (kWh) | Energy provided during the night (kWh) | Energy generated by backup generator (kWh) |
|--------------------------|-------------------------|-------------------------------|---------------------|--------------------------------------|------------------------------------------|
| Sahara                   | 2504                    | 4048                          | 1410                | 2530                                 | 1870                                     |
| Madaba                   | 1910                    | 3604                          | 1088                | 2190                                 | 1502                                     |
| Stockholm                | 2533                    | 3516                          | 1506                | 3833                                 | 2934                                     |

Table 9. Systems overview.

|                   | Sahara                      | Madaba                      | Stockholm                   |
|-------------------|-----------------------------|-----------------------------|------------------------------|
| Load consumption  | 2505 kWh/year               | 1910 kWh/year               | 2533 kWh/year               |
| Annual global irradiation | 2338 kWh/m² | 2213 kWh/m² | 975 kWh/m² |
| System capacity   | 2.0 kWp                     | 1.8 kWp                     | 3.45 kWp                     |

Figure 4. Maximum HVAC electricity demand per day.

- Hot climate zone (Arabic Sahara, Egypt)

Figure 6 describes monthly based energy plus analysis. The controlling factor of energy plus amount is air-cooling demand, as the estimated the demand for electrical equipment is constant. The cause of existing energy plus outputs is that the PV system is designed according to peak cooling demand. On the other hand, the additional energy that can be gained from the PV system is increasing as weather go outside of the summer period. The maximum energy plus that can be gained is in January (186 kWh) when the air conditioning heating demand is 1 kWh/month.

Figure 5. Monthly Energy plus analysis (Sahara)
The average energy plus that can be gained is 128 kWh/month, and the total annual estimated energy plus energy is 1543 kWh/year, with a total percentage of 38% out of the generated energy. Providing this energy to the surrounding area in the same form (electrical) or service (e.g. lighting) will be applicable in case of the availability of energy plus outputs.

• Moderate climate zone (Madaba, Jordan)

Figure 6 describes monthly based energy plus analysis, the controlling the factor of energy plus amount are both air heating and cooling demands because the estimated demand for electrical equipment is constant. The cause of existing energy plus outputs is that the PV system is designed according to peak heating demand. In January, the average monthly additional energy is almost zero, due to the high demand for air conditioning (heating), which caused by the low performance of heating in the split unit compared with cooling performance. On the other hand, the additional energy that can be gained from the PV system is increasing as we go outside of both summer and winter periods. The maximum energy plus that can be gained is in May (178 kWh) when the air conditioning heating demand is only 1 kWh/month.

The average energy plus that can be gained is 141 kWh/month, and the total annual estimated energy plus energy is 1694 kWh/year with a total percentage of 47%. The annual energy plus provided by the system is not an indicator of location’s ability to produce PV energy. Other parameters play a significant role to generate enough energy, that is, the type of heat generation and the capacity of the PV system. PV system itself is calculated based on daily electricity demand.

• Cold climate zone (Stockholm, Sweden)

Figure 7 describes monthly based energy plus analysis, the controlling the factor of energy plus amount is heating demand. The estimated demand for electrical equipment is constant. The cause of existing energy plus outputs is that the PV system was designed according to peak heating demand. In January, February, October, November and December, the average monthly additional energy is in negative, due to the high demand on air conditioning (heating) that exceeds 180 kWh/month. This was caused by the low efficiency of electrical radiator used to heat the shelter comparing with the COP of a normal split unit.

The additional energy that can be gained from PV and generator system is increasing as weather go outside of the winter period. The maximum energy plus that can be gained outside the shelter is in July (381 kWh) when the air conditioning heating demand is only 2 kWh/month.

The average energy plus that can be gained is 82 kWh/month. The total annual estimated energy plus generated (from solar energy and by using backup generator) is 982 kWh/year with a total percentage of 28%. It is worth mentioning that the generator is operating in summer in this simulation. This was done for comparison purposes only. If the generator was not operated during summer, annual estimated energy will be reduced.

4 CONCLUSION

People in rural areas may not always have electricity to power the most important equipment in their life. Renewable off-grid systems could solve this problem by generating electricity from the sun. After the study analysis for different climate zones, a renewable off-grid system was applied to cover all load consumption of the shelter and try to produce plus energy from each.

In this research, designing a worldwide plus energy prefab shelter powered with solar energy was studied thoroughly along with studying the load consumption and the annual global irradiation...
in the three climate zones (cold, moderate and hot) represented by Stockholm, Sweden, Madaba, Jordan, and Sahara Desert, respectively.

Load consumption was calculated depending on the equipment consumption and air conditioning. Air conditioning contributed the most in the energy consumption in all climate zones. The highest consumption was found in Stockholm with 1300 kWh/year, the lowest was in Madaba with 678 kWh/year and 1272 kWh/year for conditioning in Sahara that makes about the half of the total energy consumption. According to the simulating and analysis of the data, the target of producing plus energy from the shelters in each climate zone was achieved differently: in Madaba, 1694 kWh/year is a plus energy which makes about 47% of the total produced energy; in Stockholm, 982 kWh/year with 28%; and in Sahara, 1543 kWh/year with 38%.

Author Contributions

All Authors have worked as a research team and have done the work together.

Conflicts of Interest

The authors declare no conflict of interest.

REFERENCES

[1] Atmaca A, Atmaca N. Comparative life cycle energy and cost analysis of post-disaster temporary housing. Appl Energy 2016;171:429–43.
[2] Lubrizzo C, Petraglia A, Vetromile C et al. 2008. Telecommunication power systems: energy saving, renewable sources and environmental monitoring. In INTELEC 2008–2008 IEEE 30th International Telecommunications Energy Conference. 1–4. IEEE.
[3] Pons O, Wadel G. Environmental impacts of prefabricated school buildings in Catalonia. Habitat Int 2011;35:553–63.
[4] Ghafoor A, Munir A. Design and economics analysis of an off-grid PV system for household electrification. Renew Sust Energ Rev 2015;42:496–502.
[5] Saleh SY, Gadi M. An investigation into thermal comfort of shelters in refugee camps in Palestine using questionnaires and computer simulation. IJUJ Nat Stud 2016;20. 127–152.
[6] Yang W, Wong NH, Jusuf SK. Thermal comfort in outdoor urban spaces in Singapore. Build Environ 2013;59:426–35.
[7] Chandel S, Sarkar A. Performance assessment of a passive solar building for thermal comfort and energy saving in a hilly terrain of India. Energy Build 2015;86:873–85.
[8] Karthikeyan V, Navaneetha K, Singam B et al. 2016. The study and review of energy efficient cooling techniques for telecom tower shelters. In 2016 3rd International Conference on Electrical Energy Systems (ICEES). 122–7.
[9] Pacheco R, Ordóñez J, Martínez G. Energy efficient design of building: A review. Renew Sust Energ Rev 2012;16:3559–73.
[10] Alkhalidi A, Hataqay D. Energy efficient 3D printed buildings: Material and techniques selection worldwide study. J Build Eng 2020;30:101286.
[11] Alkhalidi A, Jarad H, Juaidy M. Glass properties selection effect on LEED points for Core and Shell high rise residential building in Jordan. Int J Thermal Environ Eng 2016;13:29–35.
[12] Alkhalidi A, Aljolani O. Do green buildings provide benefits to the residential sector in Jordan? Yes, but . . . Int J Low Carbon Technol 2019;ctz080. https://doi.org/10.1093/ijlct/ctz080.
[13] Kazanci OB, Skrupskelis M, Sevela P et al. Sustainable heating, cooling and ventilation of a plus-energy house via photovoltaic/thermal panels. Energy Build 2014;83:122–9.
[14] Alkhalidi A, Qoaider L, Khashman A et al. Energy and water as indicators for sustainable city site selection and design in Jordan using smart grid. Sustain Cities Soc 2018;37:125–32.
[15] World Weather and Climate Information. (2019, 20-09-2019). World Weather and Climate Information. https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine. Madaba, Jordan.
[16] Solargis. Bankable Solar Data for Better Decisions. https://solargis.com/.
[17] Meteonorm Software, 6.1 ed. Meteotest AG. last visited date 10 April, 2020
[18] Ossen DR, Hamdan Ahmad M, Madros NH. Optimum overhang geometry for building energy saving in tropical climates. J Asian Archit Build Eng 2005;4:563–70.
[19] Kottek M, Grieser J, Beck C et al. World map of the Köppen–Geiger climate classification updated. Meteorol Z 2006;15:259–63.
[20] Amman J (ed). Maani Building. In: Maani Ventures. 2019.
[21] Wu J-W, Sung W-F, Chu H-S. Thermal conductivity of polyurethane foams. Int J Heat Mass Transf 1999;42:2211–7.