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Installing and Testing the Grashof Portable Incubator Powered Using the Solar Box "Be-Care" for Remote Areas without Electricity

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Abstract: Grashof portable incubator is one of the community engagement products from the Faculty of Engineering Universitas Indonesia. Tropical Renewable Energy Center (TREC) Universitas Indonesia designed a solar box "Be-Care" that can be used as an independent power source solution for the grashof incubator. The purpose of this study is to test the performance of solar box Be-Care if it is used for incubator purposes that can at least supply 12 hours of electricity at night. Solar box Be-Care uses two batteries, each of which has a 12V voltage and 18Ah current capacity. Two types of solar panels with a capacity of 40 Wp and 100 Wp to be determined each night and day's performance. Tests were carried out in a non-AC room for three days non-stop to determine the charging and discharging characteristics of the solar box Be-Care. The test results show that with a 40 Wp capacity, the incubator performs only 22 hours 13 minutes to 11-volt battery capacity. But during the day in sunny weather conditions, 40 Wp solar panels cannot fill the voltage to the battery, so it is not feasible to use because it failed to carry out the charging process. In testing with 100 Wp solar panels, the incubator performs well for 31 hours 50 minutes. And during the day in sunny conditions, 100 Wp solar panels can charge voltage to the battery. The solar box Be-Care with 100 Wp solar panels can be used but still need more refinement to increase the performance and endurance.

Keywords: Premature Infant; Grashof Incubator; Solar Panel; Solar Box Be-Care; Solar Power Plant

1. Introduction

Newborns baby in medical terms is called the neonatal period. The neonatal period is calculated from birth until the baby is 28 days old¹). Data in 2017, the Indonesian Health Demographic Survey (IHDS), explains that Indonesia's neonatal mortality rate (NMR) is declining. In 2012, NMR in Indonesia reached 19 cases of death from every 1000 births. And in 2017, it has decreased to 15 cases of death from every 1000 births²). Although statistically, it has declined, NMR in Indonesia is still high compared to other countries. According to data from the United Nations Children's Fund (UNICEF) in 2017, NMR in Thailand was only around 6 cases of death from every 1000 births, Malaysia 5:1000, even Singapore only 2:1000³). In the 2018 report, UNICEF stated that 47% of children under-five (toddler) deaths were dominated by the neonatal period⁴). And NMR cases are more common

in rural than urban areas⁵). One of the leading causes of death during the neonatal period is premature babies¹). Premature babies need an incubator as a means of heating to maintain their ideal body temperature.

Community engagement based products from Universitas Indonesia in the form of free lending incubator to parents' homes are solutions in reducing neonatal mortality⁶). Humanitarian activities have started since 2012 in the form of free lent for baby incubators specifically designed to be used at home to the underprivileged^{7,8}).

The incubator is specially designed. Some of the advantages are portable, small dimensions, lightweight, and power saving. The incubator is called the Grashof Incubator⁹). Fig. 1 shows one of the grashof incubators used by premature babies in Indonesia. In general, the use of grashof incubators takes 1 - 1.5 months until the premature baby's weight reaches 2.5 kg.



Fig. 1: Premature baby in grashof incubator.

Electricity needs in Indonesia are managed by the National Electricity Company / Perusahaan Listrik Negara (PLN). So far, the grashof incubator uses electricity from PLN, and there has not been any development of an independent power supply for the device. According to data from the Ministry of Energy and Mineral Resources in 2017, Indonesia's electrification ratio reached 95.35%. But some provinces in Indonesia have a rate below 90%, even East Nusa Tenggara and Papua are far below 62%¹⁰. This shows that there are several areas where local people do not yet have access to electricity because there is no electricity network built by PLN.

In previous studies, various kinds of experiments have been carried out regarding heating sources independent of direct electricity. One of them is circulating warm water through copper pipes, aiming to provide warmth in the cabin¹¹. But this isn't easy to realize because the design is far from ideal. One of the proven research uses phase change material (PCM) as a source of warmth¹²⁻¹⁴. Although the temperature is reached according to the baby's needs in the cabin, the use of PCM in large quantities is not efficient in actual conditions. The total mass is twice that of an electric grashof incubator. Research that has used solar energy with photovoltaic devices was applied to egg incubators. And no one has tried to apply it for infant incubator purposes¹⁵.

Based on solar radiation data collected in 18 locations, Indonesia is a tropical country with immense solar power¹⁶. As a tropical country, Indonesia has high solar power potential with average radiation of around 4.5 - 5.0 kWh/m²/day¹⁷. This potential is equivalent to 1000 W photovoltaic (PV), producing 4000-5000 Wh electrical energy in one day¹⁸. One of the potential uses is applied to the design of a solar AC system in the tropical region¹⁹. Solar energy utilization can be a solution in suitable geographic conditions to save energy and promote green energy²⁰. The sun's potential can be used as an independent source of electricity for grashof incubators by using solar photovoltaics. Many choices of solar panel products are already on the market but rarely are portable.

The Tropical Renewable Energy Center (TREC) research group at the Universitas Indonesia has developed a solar rechargeable portable power bank called "Be-Care"²¹. This product has been used well in supplying electrical energy needs in emergencies for victims of the

earthquake and tsunami disasters in Palu and Donggala as temporary electricity supplies at the time²². Small dimensions, portable, and PNP (plug and play) become one of the advantages. Fig. 2 shows a solar box "Be-Care" rechargeable mode. Solar panels are collecting free energy from the sun.



Fig. 2: Solar box "Be-Care".

This tool will be installed and tested for use with the grashof incubator in actual conditions. The purpose of this study is to determine the performance and feasibility of the solar box "Be-Care" as an independent electricity supply for grashof incubators.

2. Basic Theory

2.1 Grashof Incubator

Grashof incubator has the excellence to enable the portability, save energy, and be used for any unprivileged family from the very beginning²³. German Scientist Franz Grashof developed the theory behind natural convection in the 19th century. Hence the name Grashof incubator was used to honor him. Here is the outline for Grashof Incubator described as following in Fig. 3.

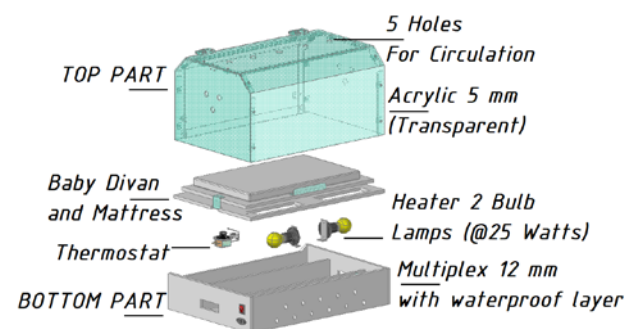


Fig. 3: Grashof Incubator's Components

The Grashof Portable Incubator uses the working principle of heat transfer by radiation, convection, and natural circulation. The heating component uses two incandescent lamps of 25 watts each. The incandescent lamp will warm the air in the heating chamber through the principles of radiation and natural convection. The air in the heating chamber will be warmer, and the temperature will rise so that the density becomes lighter. Warm air will naturally move upwards towards the baby's cabin. This

symptom is called Buoyancy Force²⁴⁾. There is an opening for fresh air supply in the heating chamber and a hole above the baby's cabin for air circulation. This makes natural circulation that works continuously to keep the temperature stable, assisted by an analog thermostat as a cut-off²⁵⁾. Technical specifications can be seen in Table 1.

Table 1. Grashof incubator technical specification.

| Point | Specification |
|--------------------|-------------------------------------|
| Power requirements | AC 50 Hz; 220-240 V |
| Heating Element | 2 Incandescent Bulbs @ 25 Watt each |
| Cut-Off / Safety | 40°C Analog Thermostats |
| Dimension (LWH) | 65 cm x 45 cm x 42 cm |
| Net weight | 14 kg |
| Upper Material | Acrylic (5 mm thickness) |
| Bottom Material | Multiplex (12 mm thickness) |

2.2 Solar Box "Be-Care"

The working principle of the solar box "Be-Care" is the same as an off-grid solar power plant system. Solar power plants with off-grid system installation is a system that is often used for remote areas that are not reached by the PLN network.

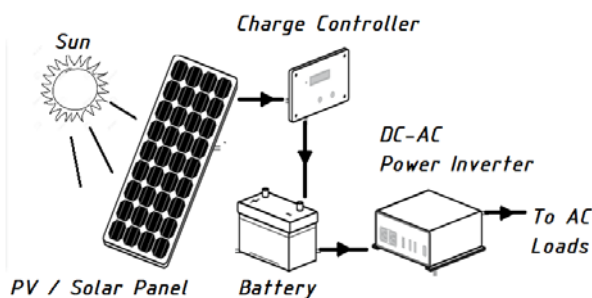


Fig. 4: Schematic diagram of off-grid solar power plants systems

The off-grid system is also referred to as a stand-alone photovoltaic (PV) system, a power generation system that relies on solar energy as the only primary energy source. Table 2 shows the technical specification "Be-Care".

Table 2. The technical specification "Be-Care".

| Point | Specification |
|-------------------------|---------------------------------|
| Solar Panel (Capacitiy) | 2 Panels @ 20 Wp - Parallel |
| Solar Panel (Current) | 1.15 A each panel |
| Battery | 2 Units @ 12V / 18Ah - Parallel |
| Solar Charge Controller | 12V / 10A |
| Output | 12V DC |
| Dimension | (500x360x140) mm |

Weight

25 kg

Solar panels' electrical energy can be used directly to the load to meet electricity needs and can be stored in batteries as backup energy simultaneously. Fig. 4 described the main components of off-grid solar power generation systems: solar panels, solar charge controllers, batteries, and inverters²⁶⁾.

3. Methodology

3.1 Battery Capacity Limit

The battery used has a maximum capacity of around 14 volts without any load. Deep of discharge (DOD) is a provision that limits the maximum level of discharge depth that can be applied to a battery. DOD settings play a role in maintaining the lifetime of the battery. The deeper the DOD is applied to a battery, the shorter the life span of the battery²⁷⁾.

Therefore the use of deep-cycle batteries can discharge up to 80% of battery capacity²⁸⁾. In this case, the lower limit of the battery capacity will be 11 volts.

3.2 Charging and Discharging

Each rechargeable battery has its characteristics influenced by the material and quality of the components inside²⁹⁻³²⁾.

The solar box "Be-Care" is designed using two 20 Wp solar panels that can be folded. Besides, this study also used 100 Wp solar panels as a performance comparison. Both of them still use two batteries as power storage. The test was carried out in 2 stages in each solar panel 40 Wp and 100 Wp. The first test is to find out how long the duration of charging (without load) starts from the lower limit (11 volts) to the maximum capacity stored by the battery. Fig. 5 shows the difference in dimensions between 40 Wp and 100 Wp solar panels.



Fig. 5: Solar panels 40 Wp and 100 Wp.

Next, the second test is charging and discharging simultaneously. The load given is an incubator when used generally in a room without air conditioning (AC). The incubator works for several days non-stop to see the charging and discharging conditions obtained during the day and full discharging at night. The feasibility of the

solar box "Be-Care" will be analyzed from the charging capability greater than discharging so that a continuous process occurs. That way, the voltage of the battery does not reach the lower limit.

3.3 Experimental Setup

Fig. 6 shows the placement of solar boxes "Be-Care" in different locations with grashof incubators. The "Be-Care" solar box is placed on the roof (red line area) so that it can simultaneously charge during daylight. The grashof incubator is placed in a non-AC room (blue line area), and the extension cable (gray line) is used as an electrical conductor from the roof to the room.

Fig. 7 shows a systematic diagram of data collection in the "Be-Care" solar box. The solar box "Be-Care" is illustrated in the red box. Inverter to change the 12V DC battery voltage to 220V AC as needed by the grashof incubator. Two voltage sensor units are used to measure each battery's voltage during the charging and discharging process. To determine the actual condition on the roof, a DHT22 sensor unit is used to collect temperature and humidity data around the solar box "Be-Care" and has been calibrated³³.

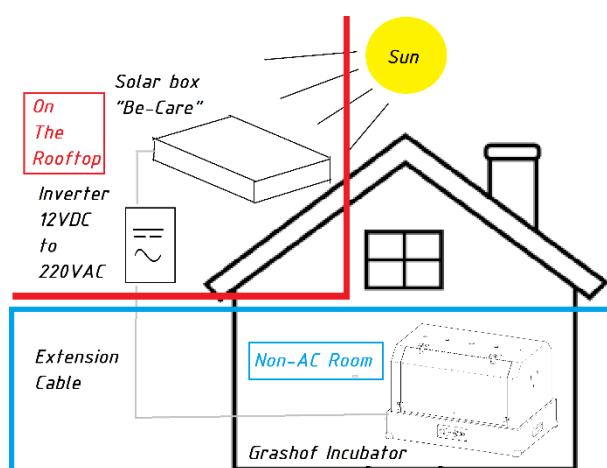


Fig. 6: Placement of the solar box "Be-Care" and grashof incubator.

All sensors are connected to Arduino Uno, which is equipped with shield data logging. The data logger has used the Faculty of Engineering's heat transfer laboratory product, University of Indonesia. The data logger is an integrated electronic device with sensors and recording data from time to time.

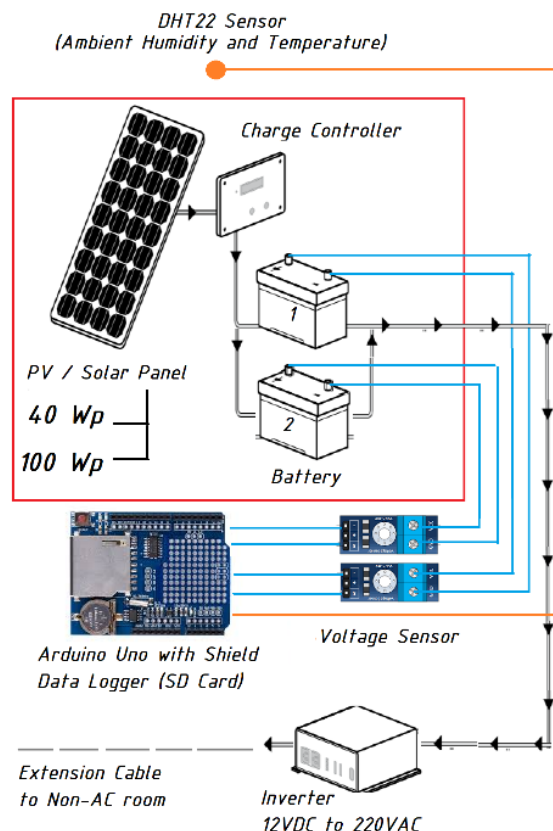


Fig. 7: Schematic diagram of the solar box "Be-Care" experiments.

Fig. 8 shows a schematic diagram of data collection for grashof incubators. W1209 Digital thermostat as a temperature controller has been integrated with the grashof incubator³⁴. As a heater, the incandescent lamp does not turn on continuously but will turn off automatically at a temperature of 35°C and turn on automatically again at a temperature of 33°C. These conditions can be programmed on the W1209 digital thermostat³⁵. Incubator temperature settings are as needed³⁶.

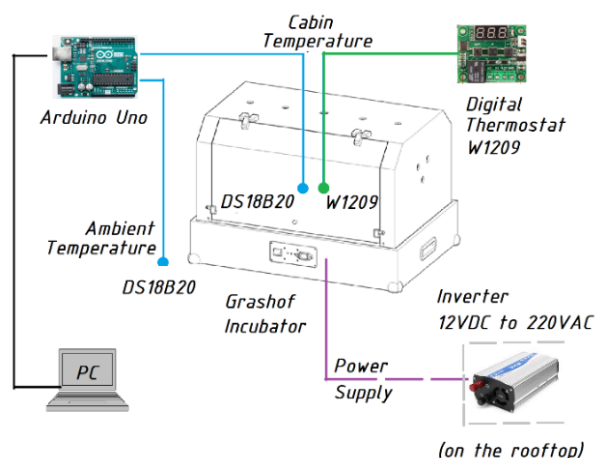


Fig. 8: Schematic diagram of the grashof incubator experiment.

Two DS18B20 sensor units are used to measure ambient temperature and incubator cabin temperature. The two sensors are connected to Arduino Uno as data acquisition in real-time, which can be viewed through a personal computer (PC). The DS18B20 sensor has been calibrated properly³⁷⁾. The accuracy value of all sensors in this experiment can be seen in Table 3.

Table 3. Accuracy of all sensors used.

| Sensors | Accuracy |
|---------------------------|----------|
| Relative Humidity (DHT22) | +3.5 % |
| Temperature (DS18B20) | 0.85 % |
| Voltage Meter | 0.25 % |

4. Results and Discussion

4.1 Solar Panel Charging - 40 Wp (without load)

From the technical specifications of the "Be-Care" solar panel, it is found that the I_{mp} (maximum current) that can be produced by the "Be-Care" solar panel is 2.3 A (1.15 A for each panel, and is arranged in parallel). Based on calculations through the "Be-Care" battery and solar panel specifications, the required charging time is 15 hours 36 minutes ($36 \text{ Ah} \div 2.3 \text{ A} = 15.6 \text{ hours}$). The duration of 15 hours 36 minutes can be achieved if the sun can provide maximum solar radiation intensity (peak sun hour).

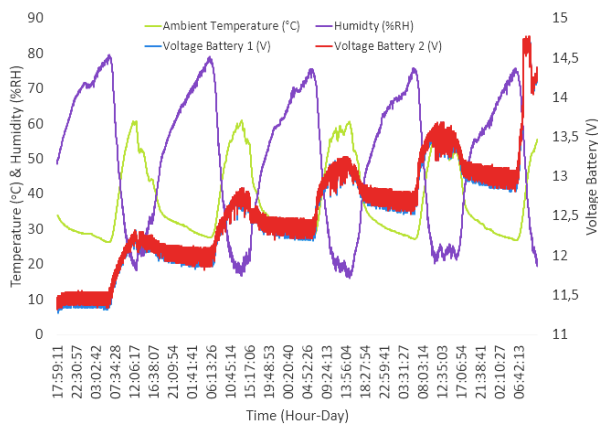


Fig. 9: Charging process using 40 Wp.

Fig. 9 shows a graph of the battery charging process results using "Be-Care" 40 Wp solar panel. In actual conditions, the duration of charging a battery from the initial capacity of 11.42 V to a total of 14.35 V lasts for 113 hours 9 minutes or four days and 17 hours 9 minutes. The intermediate charging phase in the first four days of the charging process is 0.1 V/hour ($0.8 \text{ V} \div 8 \text{ hours} = 0.1 \text{ V/hour}$). The optimum charging speed rate on a 40 Wp solar panel with an I_{mp} of 2.3 A is 0.25 V/hour ($1.25 \text{ V} \div 5 \text{ hours} = 0.25 \text{ V/hour}$).

4.2 Solar Panel Charging - 100 Wp (without load)

Fig. 10 shows a graph of the battery charging process

results using a 100 Wp solar panel.

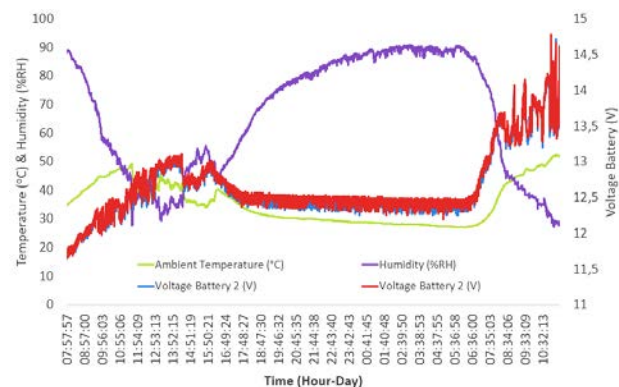


Fig. 10: Charging process using 100 Wp.

Experiments with 100 Wp solar panels were carried out because the solar panels in "Be-Care" only had I_{mp} (maximum current) of 2.3 A while on 100 Wp solar panels had I_{mp} of 5.18 A. Based on calculations through the "Be-Care" battery specifications and solar panels, the long charging time required for seven hours. ($36 \text{ Ah} \div 5.18 \text{ A} = 6.99 \text{ hours}$). From the graphic results in actual conditions, the charging time from 11.6 V to 14.6 V lasts for 26 hours 12 minutes. The optimal charging phase occurs during sunny weather over a 5 hour 28 minute period of 2.1 V, from 12.5 V to 14.6 V. The optimum charging speed is 0.38 V/hour ($2.1 \text{ V} \div 5.5 \text{ hours} = 0.38 \text{ V/hour}$).

4.3 "Be-Care" with load in actual conditions with a 40 Wp solar panel

Fig. 11 shows the incubator and ambient temperatures during data collection. Fig. 12 shows the characteristics of the "Be-Care" voltage drop as a electricity source for grashof incubators in non-AC rooms when using 40 Wp solar panels.

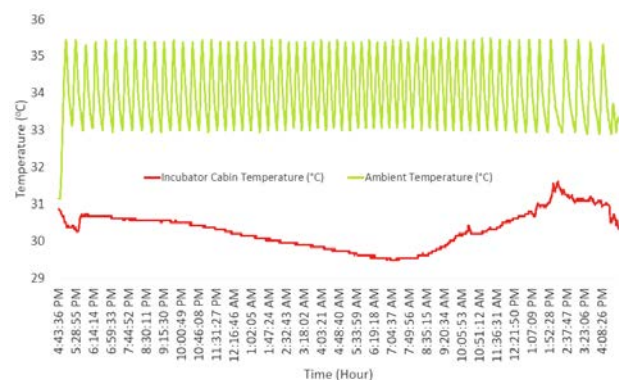


Fig. 11: Cabin and ambient temperature in room non-AC when using 40 Wp.

The duration of "Be-Care" supplies power from the float voltage capacity of 13.81 V to the lower capacity at 10.86 V is for 22 hours 13 minutes, starting at 4:43 PM until 2:56 PM the next day. The average ambient temperature of the environment was recorded at 30.3°C,

where the highest temperature was 31.6°C, and the lowest temperature was 29.5°C.

Based on the results of the graph above, "Be-Care" with 40 Wp solar panels can not be applied as a source of electricity grashof incubators in rooms without ac, because the length of time "Be-Care" supplies electricity to the incubator is not enough for the time required by the incubator. The 40 Wp solar panel on "Be-Care" has not been able to charge the battery voltage again during the daytime simultaneously with the discharging process of using an incubator so that the battery voltage continues to decrease at night or during the day until it runs out.

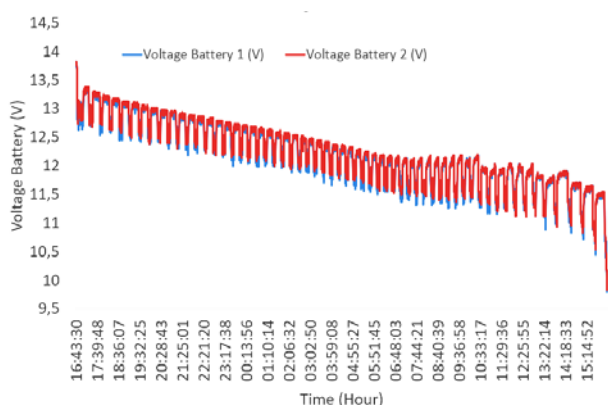


Fig. 12: The voltage drop on the battery uses 40 Wp.

The voltage drop rate at night is 0.08 V/hour ($1 \text{ V} \div 12 \text{ hours} = 0.08 \text{ V/hour}$) from the voltage of 13.2 V at 17:58 PM to 12.2 V at 05:58 AM the next day. When the sun begins to rise, the voltage drop rate is 0.13 V / hour ($1.4 \text{ V} \div 10.1 \text{ hours} = 0.13 \text{ V/hour}$) from the 12.2 V voltage at 05:58 PM to 10.86 V at 4:03 PM. Based on the above results, the rate of decline during the day and night is not much different, which shows that during the day, the 40 Wp "Be-Care" solar panel does not appear to be charging the battery but only discharges.

4.4 "Be-Care" with load in actual conditions with a 100 Wp solar panel

Fig. 13 shows the incubator, ambient temperatures during data collection, and Fig. 14 shows the characteristics of the "Be-Care" voltage drop as a source of electricity for grashof incubators in non-AC rooms using a 100 Wp solar panel.

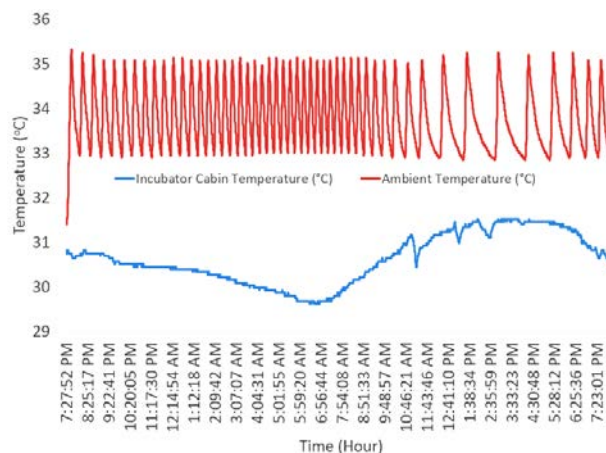


Fig. 13: Cabin and ambient temperature in room non-AC when using 100 Wp.

The duration of "Be-Care" supplying power from a capacity of 14.9 V to capacity below 12.9 V is 31 hours 50 minutes, starting from 11:08 AM to 6:08 PM the next day. The voltage "Be-Care" on 100 Wp solar panels has increased, which means there is a charging process and can supply power to the incubator load when solar radiation's intensity is sufficient. The average ambient temperature of the environment was recorded at 31.3°C, where the highest temperature was 32.5°C, and the lowest temperature was 30.4°C.

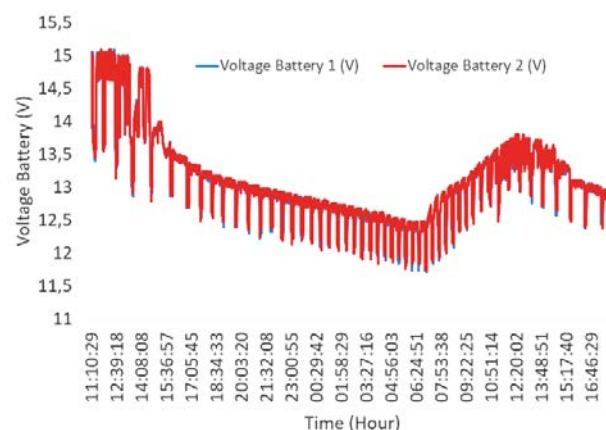


Fig. 14: The voltage drop on the battery uses 100 Wp.

Based on the graph results, "Be-Care" with 100 Wp solar panels can be used as a source of electricity for the incubator, but not yet safe. This is because the "Be-Care" solar box can charge and discharge during use in blazing conditions. If rain or cloudy weather occurs, the charging process will be interrupted. There is no optimal charging voltage for the battery, and the battery will run out so that it cannot supply electricity to the incubator.

The voltage drop rate at night is 0.06 V/hour ($0.8 \text{ V} \div 12 \text{ hours} = 0.06 \text{ V/hour}$) from the voltage of 13.2 V at 18:00 PM to 12.4 V at 06:00 AM. The average voltage drop rate during the day is 0.28 V/hour ($1.15 \text{ V} \div 4 \text{ hours} = 0.28 \text{ V/hour}$) from the voltage of 14.8 V at 14:00 to 13.2

V at 18:00 on the first day and from the 13.6 V voltage at 14:00 to 12.9 V at 18:00 on the second day. When the sun begins to rise during the morning until noon, the rate of voltage increase is 0.22 V/hour ($1.4 \text{ V} \div 6.3 \text{ hours} = 0.22 \text{ V/hour}$) from the voltage of 12.4 V at 06:00 AM to 13.81 V at 12:18 PM. Based on the results, the rate of decline is greater than the increase rate with a difference of 0.12 V.

5. Conclusions

The test results show "Be-Care" as an electricity source for grashof incubators with 40 Wp solar panels for 22 hours 13 minutes with ambient temperature incubator 30.3°C. Still, in sunny weather conditions, 40 Wp solar panels cannot charge voltage to the batteries during the day. "Be-Care" is not suitable for use because it failed to make the charging process. In testing with a 100 Wp solar panel, "Be-Care" can supply power to the incubator load for 31 hours 50 minutes with a record ambient temperature of 31.3°C.

During the daytime in sunny weather conditions, the 100 Wp solar panel can recharge the voltage to the battery "Be-Care", but the voltage increase rate is lower than the voltage drop speed. This indicates that using "Be-Care" with 100 Wp solar panels can be used but is not safe for long-term use (1 month).

The solar box "Be-Care" with existing technical specifications is not yet suitable as a source of electricity for grashof incubators based on variations in the results of tests that have been carried out. However, the solar box "Be-Care" can be used as a source of electricity for the grashof incubator if retrofitting and replacing large capacities of the components currently owned.

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Nomenclature

| | |
|------------|--------------------------------|
| <i>Wp</i> | Watt peak |
| <i>V</i> | Voltage |
| <i>Imp</i> | Amperage / Current Maximum (A) |
| <i>°C</i> | Degree Celcius |
| <i>kg</i> | Kilogram(s) |
| <i>AC</i> | Air Conditioning |
| <i>AC</i> | Alternating Current |
| <i>DC</i> | Direct Current |

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