During the summer holidays, a group of friends gathers in a motorhome equipped with the appliances listed in Table 1. The motorhome operates at a nominal DC voltage of 24 V. With the aim of making the motorhome energy sustainable, they plan to install a photovoltaic system to ensure a full charge. Table 2 provides information on the available photovoltaic panels, the energy storage system using batteries, and the inverter details.

|  |  |  |  |
| --- | --- | --- | --- |
| Appliances DC | Appliances Power [W | Hours/day of Use [h] | Energy used [Wh] |
| Refrigerator | 150 | 5 | 750 |
| Lamps | 60 | 3 | 180 |
| Television | 60 | 3 | 180 |
| **Total** |  |  | 1110 |

Table 1 DC Loads

AC Loads

|  |  |  |  |
| --- | --- | --- | --- |
| Appliances | Power [W] | Hours/day of Use [h] | Energy Demand[Wh} |
| Washing Machine | 300 | 0.3 | 90 |
| Microwave Oven | 300 | 0.5 | 150 |
| Electric Stove | 250 | 0.25 | 62.5 |
| **Total** |  |  | 302.5 |

Table 2 – Characteristics of photovoltaic panels, battery system, and inverter.

**Solar Irradiation**: Number of solar irradiation hours/day 6h

**Characteristics of each photovoltaic panel**

**Peak Power** =150Wp; **Peak Voltage** = 34.0 V; **Peak Current** = 4.4 A

**Battery Characteristics**: Reserve Capacity 4 days Usable Capacity 80% | Energy Losses 20%

**Inverter Details**

**Energy Losses** 15%

Solution

To determine the number of photovoltaic panels needed, we must calculate the total energy the system needs to generate daily, taking losses into account.

**1. Daily Energy Consumption by Appliances:**

* **DC Appliances:**
  + Refrigerator: 150W×5h=750Wh
  + Lamps: 60W×3h=180Wh
  + Television: 60W×3h=180Wh
  + **Total DC Energy:** 750Wh+180Wh+180Wh=1110Wh
* **AC Appliances:**
  + Washing Machine: 300W×0.3h=90Wh
  + Microwave Oven: 300W×0.5h=150Wh
  + Electric Stove: 250W×0.25h=62.5Wh
  + **Total AC Energy:** 90Wh+150Wh+62.5Wh=302.5Wh

**2. Energy Required from Panels, Considering Losses:**

The energy generated by the panels must cover the appliance consumption and system losses (inverter and batteries).

* **Inverter Losses:** AC appliances are powered through the inverter, which has 15% losses (85% efficiency).
  + AC energy required (before inverter): 302.5Wh/(1−0.150)=302.5Wh/0.85=355.88Wh
* **Total DC Energy (after inverter losses):** This is the total energy the DC side of the system (including batteries) needs to provide.
  + Total DC Energy for Load = Total DC Energy Consumed + AC Energy required (before inverter)
  + Total DC Energy for Load = 1110Wh+355.882Wh=1465.9Wh
* **Battery Losses:** Energy generated by the panels will pass through the batteries (for storage and discharge), which have 20% losses (80% efficiency).
  + Energy required from panels (before battery losses): 1465.882Wh/(1−0.2)=1488.125Wh/0.80=1832.352Wh

**3. Energy Generated by One Photovoltaic Panel per Day:**

* Peak power of one panel: 150Wp
* Solar irradiation hours/day: 6h
* Energy generated by one panel per day: 150Wp×6h=900Wh/day

**4. Number of Panels Needed:**

* Number of panels = Energy required from panels / Energy generated by one panel per day
* Number of panels = 1750.735Wh/900Wh/day≈1.945

Since it's not possible to have a fraction of a panel, we round up to the next whole number.

Therefore, **2 photovoltaic panels** are needed to ensure the total load.

**To determine the minimum battery capacity** that should be used, we need to consider **the total daily energy consumption,** the **reserve capacity**, and **the usable capacity of the battery**.

**1. Total Daily Energy Consumption:** From the previous calculation, the total energy the system must guarantee during 1 day (after accounting for inverter and battery losses) is: Energy required from panels (before battery losses) = 1832.352Wh This is the energy that needs to be supplied *from* the battery (or directly from panels) to meet the load, considering all system efficiencies. So, this is the daily energy the battery must be able to deliver.

**2. Energy Needed for Reserve Capacity:** The reserve capacity is 4 days. This means the battery system should be able to supply the daily energy consumption for 4 days without being recharged.

* Total Energy for Reserve = Daily Energy Consumption × Reserve Capacity
* Total Energy for Reserve = 1832.352Wh /dia×4dias=7329.408Wh

**3. Minimum Battery Capacity (considering Usable Capacity):** The usable capacity of the battery is 80%. This means that only 80% of the battery's nominal capacity can be effectively used to prevent deep discharge and prolong its lifespan. Therefore, the nominal capacity of the battery must be higher than the calculated energy needed for reserve.

* Minimum Nominal Battery Capacity = Total Energy for Reserve / Usable Capacity
* Minimum Nominal Battery Capacity = 7329.408Wh /0.80=9161.76Wh

Rounding up to a practical value, the minimum battery capacity that should be used is **9161.76 Wh** (or approximately 9.16 kWh).

**Battery capacity in Ampere-hours (Ah)**, we need to use the nominal voltage of the motorhome's DC system.

**From the problem description**:

* The motorhome operates with a nominal voltage of **24 V DC**.
* The minimum nominal battery capacity calculated was **9161.76 Wh**.

The relationship between Watt-hours (Wh), Volts (V), and Ampere-hours (Ah) is: Wh=V×Ah

Therefore, to find the capacity in Ah =Wh/V

Ah=9161.76 Wh /24V Ah≈381.74Ah

Rounding to a more practical number, the minimum battery capacity that should be used is approximately **381.74Ah**.

Problem 2

A request was made to design an off-grid photovoltaic system for a remote hospital in Turnistan. Your photovoltaic system needs to power an important cooling system that must keep vaccines at a constant temperature of 5∘C every hour of the day, every day of the year. The cooling system operates on direct current (DC) at 48 volts. The power consumed by the cooling system depends on the external temperature and is given by:

Pcons​=60W+(∣Text​−5∘C∣×(40W/∘C)).

In this context, Pcons​ represents the power consumed by the cooling system and Text​ indicates the average daily external temperature in degrees Celsius (∘C). Table 1 provides the values for the average daily external temperature and the equivalent sun hours, ESH, (daily solar energy (Wh/m²\*day) = equivalent sun hours (h/day)\*1000 (W/m²)) for Turnistan, which fluctuate according to the seasons.

Table 1

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Season | Winter | Spring | Summer | Autumn |
| Text​ (∘C) | 8 | 14 | 32 | 17 |
| ESH(Wh/m².day) | 1.8 | 7.0 | 7.6 | 4.5 |