Course: Elective – Technology of Solar Photovoltaic Systems

Grade: 2nd

Occupation: Heating and Air Conditioning Installer

LEARNING MATERIAL
For Secondary Adult Education

AEI Studium

First learning material

ELECTIVE – TECHNOLOGY OF SOLAR PHOTOVOLTAIC SYSTEMS

Vukovar, May 2023

INTRODUCTION

This learning letter is part of the course "Technology of Solar Photovoltaic Systems," within the three-year education program for heating and air conditioning installers. The course is delivered through correspondence-consultative learning.

The content of this material helps learners study independently with teacher support. Institutions offering this type of education must create learning materials according to specific regulations. This is stipulated by the Ordinance on Standards and Norms, and the manner and procedure of assessing compliance in adult education institutions (NN 129/08, NN 52/10).

The goal of this material is to help learners gain new knowledge and improve skills related to solar photovoltaic system technology.

The content is structured and covers key concepts, including:

- Solar energy,
- Solar collectors,
- Solar pools,
- Photovoltaic cells,
- Thermionic cells,
- Thermoelectric cells,
- Solar towers.

It also explains how solar elements are used in households, tourism, and other sectors.

Learning Tips:

- Skim through the material to get an overview.
- Plan your study time: daily, weekly, and exam planning.
- Use your preferred learning style: visual, auditory, or kinesthetic.
- Take breaks to help with long-term memory retention.
- Review with intervals and think about the content.
- Use modern learning techniques and memory aids.
- Highlight key terms and take notes.
- Connect new information with your previous knowledge and experience.

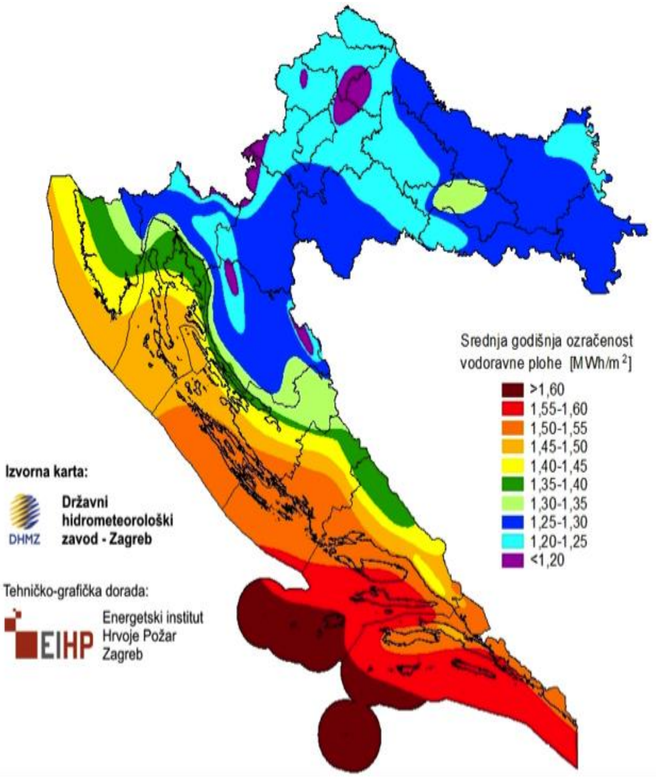
S A D R Ž A J

Stranice

➢ **1. SOLAR LIGHT AND RADIATION**	**KEY TERMS**
In this learning unit, you will learn the basics of solar energy. We will discuss: • **Solar rays** – What do they do? Which are beneficial and which are harmful? • **Infrared rays** – They give us warmth, but we can't see them. • **The sun's thermal energy** – How can we use it in different devices? Examples include: • Collectors (used to heat water), • Pools (to maintain warm water),	

• Photovoltaic systems (convert sunlight into electricity), • Thermionic and thermoelectric systems (also use heat to generate energy). You'll also learn where these systems can be installed, such as: • Family homes, • Hotels, • Swimming pools, • Recreational centers, • Greenhouses for fruits and vegetables, • Dryers for tobacco and wool. **To check your understanding of this topic, ask yourself:** • Do I know what solar energy is? • Do I understand the properties and types of solar radiation? • Do I understand what infrared rays are? • Do I know what a solar collector is and how it works? • Do I understand the basics of solar pools? • Can I explain how photovoltaic systems are made and how they work? • Do I know how photovoltaic panels create thermal and electric energy? • Do I understand how solar energy becomes thermal or electrical energy? • Do I know the differences in methods for installing solar panels? • Can I explain the specific features of different types of photovoltaic panels? • Do I know how to install photovoltaic panels on a house? **Key Concepts of This Unit:** • Solar energy • Radiation	

• Infrared rays • Photovoltaic panels • Thermal energy production using photovoltaic panels • Electrical energy production using photovoltaic cells • Solar pools • Solar towers **1.1. SUNLIGHT IN THE REPUBLIC OF CROATIA** Croatia has excellent conditions for using solar energy due to its geographic location. • In the south of Croatia, standard photovoltaic systems produce between **1100 and 1330 kilowatt-hours (kWh)** per installed kilowatt-peak (kWp) per year. • In the continental part of Croatia, the output is between **1000 and 1100 kWh/kWp** per year. A map shows the average yearly amount of solar radiation on a horizontal surface in Croatia, measured in **megawatt-hours per square meter (MWh/m²)**.	**Geographical, Topographical, and Climatic Position of the Republic of Croatia in Relation to Solar Energy**



Renewable Energy Sources

Key Information from the Map:

- **Red areas** (southern coast and islands) receive the most solar energy – over **1.6 MWh/m² per year**.
- **Orange and yellow areas** (near the coast) also get a lot of sun, but slightly less than the red zones.
- **Green and blue areas** (inland and northern Croatia) receive less solar energy, especially the dark blue zones which get less than **1.2 MWh/m²**.

The **Sun is essential for life** on Earth. It provides light and warmth, influences the climate, and helps plants grow. In just 30 minutes, the Sun delivers more energy than the world uses in an entire year!

Solar Power and Environment

Today, solar power plants supply cities with electricity. At the same time, they help reduce harmful gas emissions and protect

the environment. For every kilowatt-hour (kWh) of electricity produced from the sun, **1 kg of CO_2 emissions is avoided**. Renewable energy sources (excluding hydroelectric plants) account for only about **2% of global electricity production**, and solar energy makes up just **1%** of that. However, solar power is rapidly gaining importance. Last year alone, solar energy attracted **almost half of all investments in renewable energy** – about **130 billion dollars**, with **two-thirds** of that invested in Europe.	
The Power of Solar Radiation Solar radiation is incredibly powerful. The total energy output of the Sun is **3.8×10^{23} kW per year** or **3.3×10^{27} kWh per year**. Only a small fraction of this energy reaches Earth – but that's still **over 100,000 times** more than all power plants on Earth combined can produce at full capacity. Just **one sunny hour** delivers enough energy to meet the needs of all **6.5 billion people** on Earth!	**Most Commonly Used Solar Elements**
1.2. SOLAR SYSTEMS The most commonly used solar systems today include: • **Solar collectors** • **Solar-heated swimming pools** • **Solar towers** • **Photovoltaic systems** • **Thermionic systems** • **Thermoelectric systems** **1.3. SOLAR COLLECTORS** A **solar collector** is a device that uses the sun's energy to heat water or other liquids. There are two main types: 1. **Open system** – Water is heated directly as it flows through the collectors on the roof.	**Solar Collector**

Countries Leading in Solar Element Installation

2. **Closed system** – Collectors contain a non-freezing liquid (like glycol or antifreeze), allowing the system to work even when temperatures fall below 0°C.

How it works:

- On a sunny day, water heats up directly in the collector.
- On cloudy days, collectors help preheat water and reduce electricity use.
- They are especially useful for **heating swimming pools**, extending the swimming season by several weeks.

Usage in Europe:

- In 2000, the EU installed over **1,046,140 m²** of new solar collectors.
- **Germany and Austria** were leaders, with Germany accounting for **over 60%** of all installations.
- The EU's goal was to install **100 million m²** by 2010; about **80 million m²** had been installed by then.

Energy Transfer Medium in a Solar Collector

Parts of a Solar Collector

Components of a Forced-Circulation Solar Thermal System:

- Solar collectors (to heat the water)
- A storage tank (to keep the heat)
- An auxiliary heater
- Piping
- A pump
- A control unit that manages the system

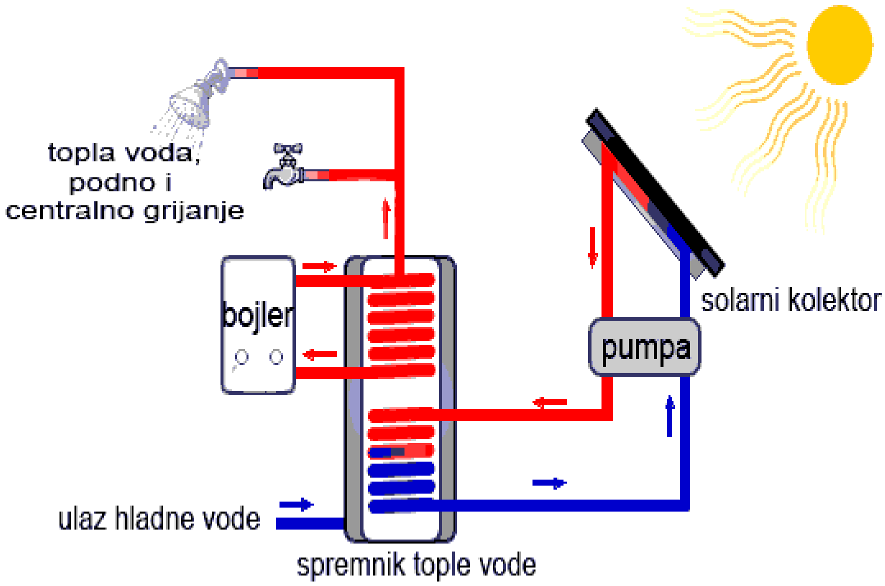


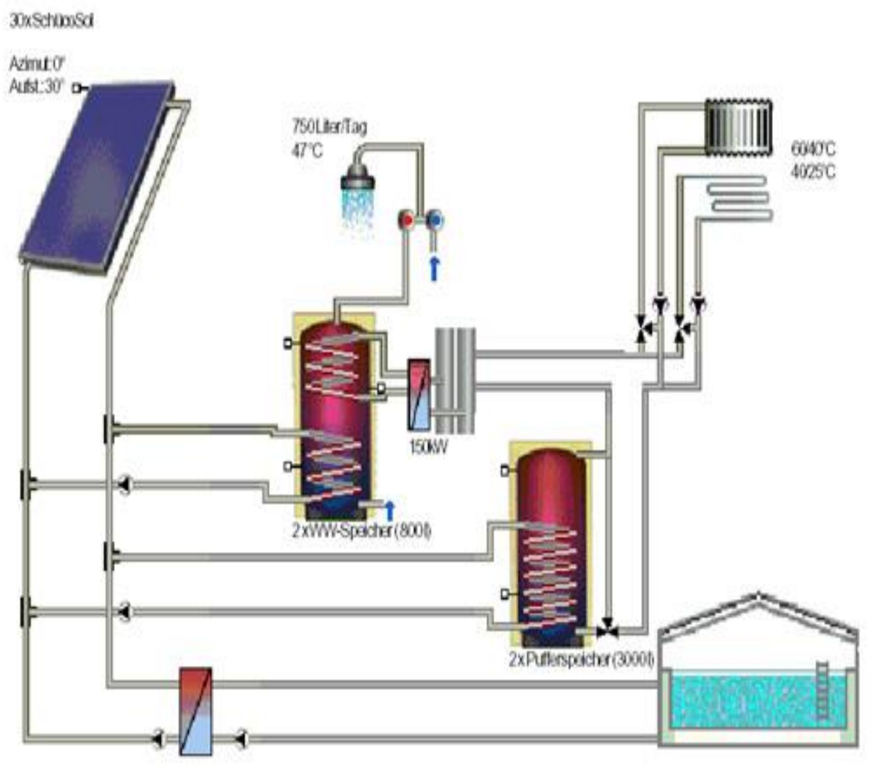
Diagram explanation:

1. **The sun heats the water** as it passes through the collector.
2. **Hot water is stored** in the tank until it's needed.
3. **Cold water** enters the collector to be reheated.
4. **Hot water flows** to taps or radiators, optionally reheated by a boiler.

Color code in diagrams:

- Blue = cold water
- Red = hot water

<table>
<tr>
<td>



This image shows a more complex system for using solar energy to heat water and warm a swimming pool. Here's how it works:

1. **Solar panels (left side)**
   The sun’s energy heats a fluid that circulates through the panels.
2. **Hot fluid flows into storage tanks**
   The heated fluid enters two large tanks (red cylinders), where it transfers heat to the water used in the household.
3. **Additional heating (burner or heater)**
   If the sun isn’t strong enough, a 150 kW burner heats the water in the tanks to maintain the required temperature.
4. **Distribution of heated water**

- One part of the hot water is used for household purposes (showers, faucets).
- The other part heats the swimming pool water (right side of the image).

5. **Circulation**
   The cooled fluid returns to the solar panels to be reheated.

Key temperatures:

750 liters at 47°C: Water for household use.

Pool water at 40–25°C: To maintain the pool’s temperature.

</td>
<td>

Temperature Generated by the Sun in a Collector

What Determines the Tilt Angle of a Collector?

</td>
</tr>
</table>

The temperature achieved in the solar collector ranges from 60°C to 90°C, depending on the strength of the infrared rays.

1.4. FLAT-PLATE SOLAR COLLECTOR

Flat-plate collectors are used to heat water and living spaces. They are usually installed on rooftops. The **roof should face south** and be tilted downward. These collectors absorb **direct sunlight** as well as **diffused light** from the sky.

How to choose the right tilt angle?

The tilt angle should match the season when you need the most energy. In Croatia, this is typically **between 35° and 45°**. This ensures about 7–8 hours of sunlight from spring to autumn.

- For **better winter performance**, collectors can be installed at a steeper angle.
- Even vertically mounted collectors on a south-facing wall can work well in winter.
- The best results come from **calculating the optimal angle** for your specific location.

Parts of a Flat-Plate Collector

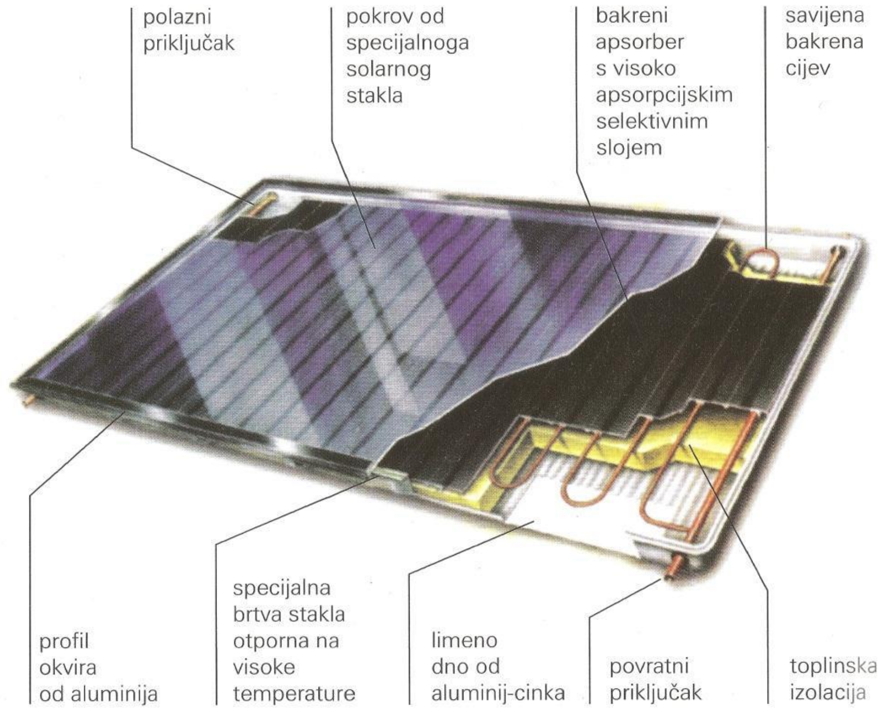
Choosing a Collector: Cost vs. Efficiency

When selecting a collector, it's important to balance:

- Collector efficiency
- Price of the collector
- Total system cost

Definition:

A solar collector is the **core component** of a solar heating system. It converts sunlight into heat. The technology is well developed, mass-produced, and widely available.

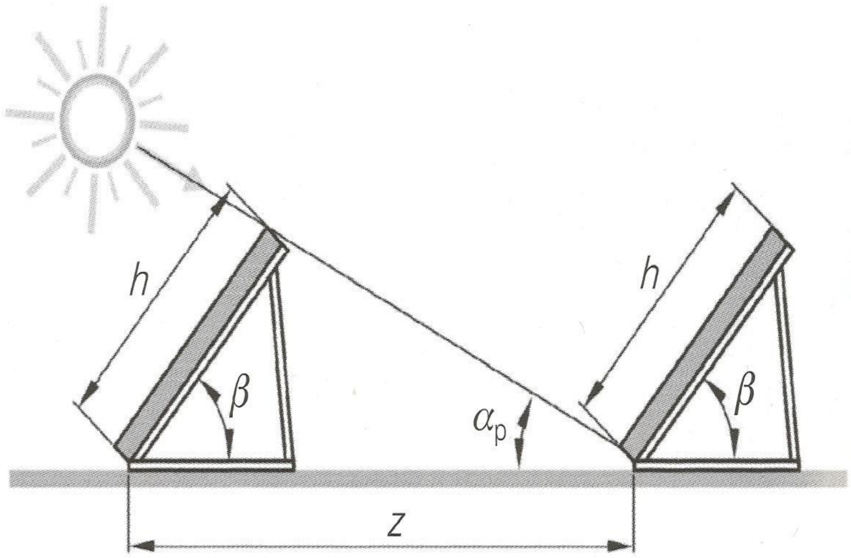


Cross-section of a Flat-Plate Collector (diagram description):

Main components:

- Inlet connector
- Special solar glass cover
- Copper absorber with selective high-absorption coating
- Bent copper tubing
- Aluminum frame
- High-temperature resistant glass seal
- Aluminum-zinc metal bottom
- Outlet connector
- Thermal insulation

Characteristics of Photovoltaic Cells



Collector Row Spacing Parameters

1.5. PHOTOVOLTAIC CELLS

Advantages of a Photovoltaic System

A **solar panel** is made up of several connected **photovoltaic cells**—typically around **36 per panel**. These are connected to create a **12V module**. Each cell has an output voltage of around **600–700 millivolts (mV)**. By connecting multiple cells, we get the voltage needed for the panel.

Because one photovoltaic cell produces only a small amount of power, they are grouped into modules (solar panels). Multiple panels form an array, which can be part of a **solar power plant**.

Working Principle of Photovoltaic Panels

Photovoltaic cells are usually made from monocrystalline silicon wafers.

Advantages of Photovoltaic Systems:

- High reliability
- Low operating costs and high efficiency
- Minimal maintenance, no fuel required
- Best renewable energy source for urban environments
- No moving parts – simple mechanics
- Can be used almost anywhere on Earth
- Silent and environmentally friendly energy production
- Ideal for remote areas where power supply is difficult or expensive

2. PHOTOVOLTAIC PANELS

2.1. Technology of Photovoltaic Cells and Panels

Photovoltaic panels use solar energy to produce electricity. The solar cells in the panels convert sunlight into electrical energy.

Solar cells can be made from different materials, such as monocrystalline, polycrystalline, or amorphous materials. Silicon is the most commonly used, though there are other materials as well.

When sunlight hits the solar cells, small electrons are released, creating an electric current. When the cells are connected to an electric device, they generate electrical energy that can be used to power it.

Photovoltaic Power Plants

Solar photovoltaic power plants consist of panels connected into larger groups called arrays. These arrays can be:

• **Off-grid (stand-alone)** – Not connected to the grid. They represent about 5% of total installations and usually use batteries and inverters to improve performance. • **Grid-connected** – The energy goes directly to the grid or to the users. **Power of a Photovoltaic Panel** One photovoltaic panel has a power range between 50 and 300 W. A panel consists of multiple solar cells or a single cell in a thin-film form. **Panel Mounting Types** • **Fixed mounting** – Panels are installed at an optimal angle for maximum energy production. • **Tracking systems** – These systems follow the sun, can produce 20–30% more energy, but are more expensive and require more maintenance. Grid-Connected System A grid-connected system is linked to the public electricity grid via household installations. The electricity produced by the photovoltaic system is first used to power the devices in the home. Any surplus energy is sold to the grid.	**Basic Types of Photovoltaic Panels**
The grid acts as an energy storage system. If the photovoltaic modules do not produce enough energy, the rest is taken from the grid. Basic Elements of a Grid System: 1. Photovoltaic modules 2. Mounting components 3. Cables 4. Junction box with protective equipment 5. DC/AC inverter – Converts direct current from the	**Material Used for Manufacturing Photovoltaic Cells**

modules into alternating current compatible with grid voltage and frequency

6. Energy meter – Measures produced and consumed energy
7. Grid connection – Systems are connected to the low-voltage power system

2.2. MAIN TYPES OF PHOTOVOLTAIC PANELS

a) Monocrystalline Silicon (Si) Panels

This type of panel converts solar energy into electrical energy. Each 1 m² of panel can produce **140 W** of electricity from **1000 W** of solar radiation.

The panel is made from high-purity silicon. The silicon is melted and then cut into thin wafers, which enable high efficiency in converting solar energy into electricity.

b) Polycrystalline Silicon (Si) Panels

This type of panel can convert **1000 W** of solar radiation per m² into **130 W** of electricity.

Manufacturing polycrystalline panels is cheaper than monocrystalline ones. Liquid silicon is poured into blocks and then cut into wafers. As silicon cools, it forms crystalline structures of different sizes. Errors occur at the boundaries between these crystals, which is why these panels are less efficient in converting solar energy into electricity.

c) Amorphous Silicon (Si) Panels

This type of panel can convert **1000 W** of solar radiation per m² into **50 W** of electricity.

A thin layer of silicon is deposited onto glass or another surface—this is called an **amorphous or thin-film cell**. The silicon layer is very thin, less than 1 μm, which makes production cheaper. However, these cells absorb less solar energy than other types. They are often used in low-power devices like watches and pocket calculators or integrated into building facades.

d) Gallium Arsenide (GaAs) Panels

Gallium arsenide is a special material made from **gallium (Ga)** and **arsenic (As)**. It is used in **high-efficiency** solar panels because of its excellent ability to absorb sunlight.

The panel thickness is very small—only a few micrometers—yet it can absorb solar energy efficiently. It is also less sensitive to heat and radiation compared to silicon.

Panels

Due to its high cost, gallium arsenide is used in **special applications**, such as **space programs** and **concentrated solar radiation systems**, which are still in the research phase.

This panel type can convert **1000 W** of solar radiation per m² into **300 W** of electricity.

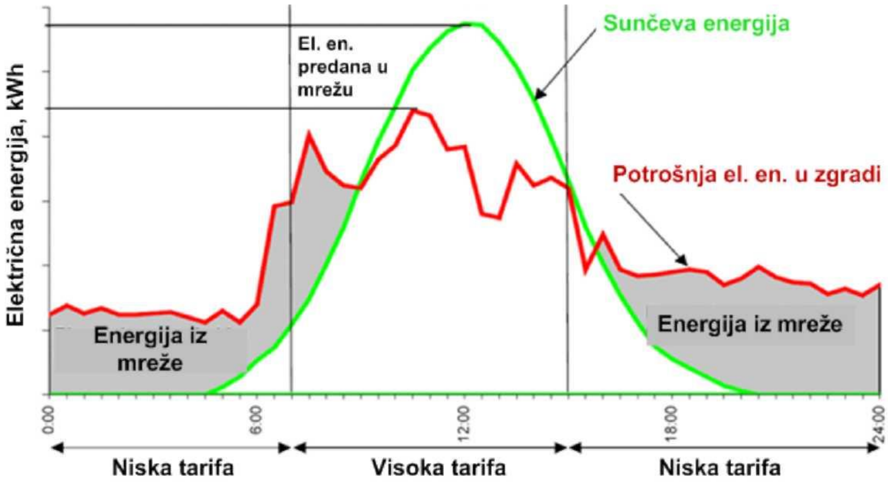
e) Cadmium Telluride (CdTe) Panels

This panel can convert **1000 W/m²** of solar radiation into **160 W** of electricity per m² in laboratory conditions.

Cadmium telluride is made from **cadmium** (a metal) and **tellurium** (a metalloid). It is suitable for thin-film modules due to its favorable physical properties, and the production technology is relatively inexpensive.

However, due to the **toxicity of cadmium**, its use is limited. This is an important factor when considering its application.

2.3. COMPARISON OF ELECTRICAL POWER, COST, AND QUALITY



This chart illustrates three important aspects:

1. **Electricity consumption in a building** (red line)
2. **Energy produced by the sun** (green line)
3. **Energy from the grid** (gray areas below the red line)

Explanation:

- **Solar energy (green line):** Shows how much energy solar panels produce during the day. The most energy is generated around noon, when sunlight is strongest.
- **Electricity consumption (red line):** Shows how much electricity the building uses during the day and night.
- **Energy from the grid (gray):** When the building consumes more electricity than the solar panels produce, the difference is supplied by the grid.

Electricity Tariffs:

- **Low tariff:** Cheaper electricity (from 00:00 to 06:00 and 18:00 to 24:00)
- **High tariff:** More expensive electricity (from 06:00 to 18:00)

If solar panels produce more energy than the building uses (when the green line rises above the red line), the excess energy is fed into the electrical grid.

The capacity of photovoltaic installations has been growing by more than **40% per year** (several gigawatts annually), which raises concerns about the **supply of silicon**. Thin-film technologies are advancing rapidly. Although still not economical, they are expected to become cost-effective within **5 to 10 years**. By the end of 2010, total installed capacity was around **19 GW**.

Sample Solar Cell Specifications

Parameter	**Value**
Peak power (Wp)	**3.8 W**
Open-circuit voltage (Voc)	**0.605 V**
Short-circuit current (Isc)	**8.9 A**
Voltage at maximum power (Vmp)	**0.472 V**

Current at maximum power (Imp) **8.05 A** **Efficiency** **14.6%** **Thickness** **450–600 microns** **Cell size** **165 × 165 mm** **Explanation:** 1. **Peak power (Wp):** Maximum output – 3.8 W 2. **Open-circuit voltage (Voc):** Voltage with no load – 0.605 V 3. **Short-circuit current (Isc):** Maximum current when short-circuited – 8.9 A 4. **Voltage at max power (Vmp):** Voltage when generating peak power – 0.472 V 5. **Current at max power (Imp):** Current at maximum output – 8.05 A 6. **Efficiency:** 14.6% – how well the cell converts sunlight into electricity 7. **Thickness:** 450–600 µm 8. **Size:** 165 mm x 165 mm **BE EFFICIENT!** You have completed the first learning unit, which included a few basic terms and several important pieces of information to remember. **WE SUGGEST:** • Carefully re-read the text of this learning unit, • Identify the key points, • Reflect on each key concept, • Describe it in your own words, • Write a short note in your own words, and only then • Move on to the next learning unit.	

REVIEW AND CONSOLIDATION TASKS

- Describe the advantage of using solar energy in households.
- List the characteristics of solar infrared radiation.
- Name the main parts of a solar collector.
- Describe how the collector works and the principle behind it.
- Explain what photovoltaic (PV) panels are made of and how they work.
- Explain the differences between amorphous silicon and gallium arsenide panels.
- Describe the process of generating electricity using solar energy.
- How can photovoltaic panels be distinguished from one another?
- Recognize the usefulness and efficiency of solar energy as a renewable energy source that does not pollute the environment.

3. LIST OF LITERATURE

- Majdandžić, Ljubomir: *Solarni sustavi,* Zagreb, Graphis d.o.o., 2010.,
- PRIOR inţenjering d.o.o., Zagreb: *Autodesk Inventor*, 2012.,
- URL: http://www.prior.hr/programi/autodesk-inventor
- Beder, Steve: *Autodesk Manufacturing & Digital Prototyping Solution*, 2012., (Slike)
- URL: http://autodeskmfg.typepad.com/blog/. (10.05.2012.).
- Milan, Opalić; Milan Kljajin, Slavko Sebastijanović: *Tehničko crtanje*, Čakovec/Slavonski Brod, Zrinski d.d., 2007.,

4. SELF-ASSESSMENT TASKS WITH PAGE REFERENCES FOR ANSWERS

1. **What is solar energy?**

   ____

   ____

____

2. **Is Croatia's topographical and geographical position favorable for using solar energy?**

   a) YES **b) No**

3. **Solar energy belongs to ________________ energy sources, unlike coal which is a non-renewable energy source.**

4. **Which solar systems are most commonly used in practice today?**

____

____

____

____

____

____

5. **Circle the country that leads in the installation of solar elements:**

a) France b) Germany c) Italy

6. **What is the medium that transfers solar energy in a solar collector?**

____

____

7. **What determines the tilt angle of a solar collector?**

____

____

____

8. List 5 advantages of photovoltaic systems: ____ ____ ____ ____ ____ **9. What is the composition of a Cadmium Telluride (CdTe) panel?** ____ ____ ____ ________ **10. Cross out the odd one out:** **a) Cover strips b) Frame profile c) Mounting part** **d) Metal bottom e) Collector mounting plate**	