HI-SMART

HI-SMART: HIGHER EDUCATION PACKAGE FOR NEARLY ZERO ENERGY AND SMART BUILDING DESIGN

MODULE #4

CHAPTER 4: ELECTRICITY AND COMBINED HEAT AND ELECTRICITY GENERATION IN BUILDINGS

Co-funded by the Erasmus+ Programme of the European Union

MŰEGYETEM 1782 STU SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA TECHNISCHE UNIVERSITÄT KAISERSLAUTERN ENERGIAKLUB CLIMATE POLICY INSTITUTE APPLIED COMMUNICATIONS

CONTENT

Building scale electricity generation 3

PV systems 3

Solar PV-T 18

Wind turbines 21

Cogeneration 25

BUILDING SCALE ELECTRICITY GENERATION

PV SYSTEMS

Nowadays the most widespread electricity generation on the building scale is by PV systems. The operation of a PV system is based on the photovoltaic effect, which has a semiconductor base (usually silicon) and transforms the incoming solar radiation to electricity.

CELL TYPES

The two main cell types are the crystalline silicon cells and the thin layer cells. Within these two categories there are several subcategories, which are shown on Figure 4.4.1. The most widespread cells are the crystalline silicon cells, which have two main types: the monocrystalline and the polycrystalline cells. The monocrystalline cells are made from a single crystal, while the polycrystalline cells are made of several crystals. Due to their manufacturing process the monocrystalline cells are slightly more expensive than the polycrystalline cells, however they also have slightly higher cell efficiency, 15-18% and 13-16% respectively.

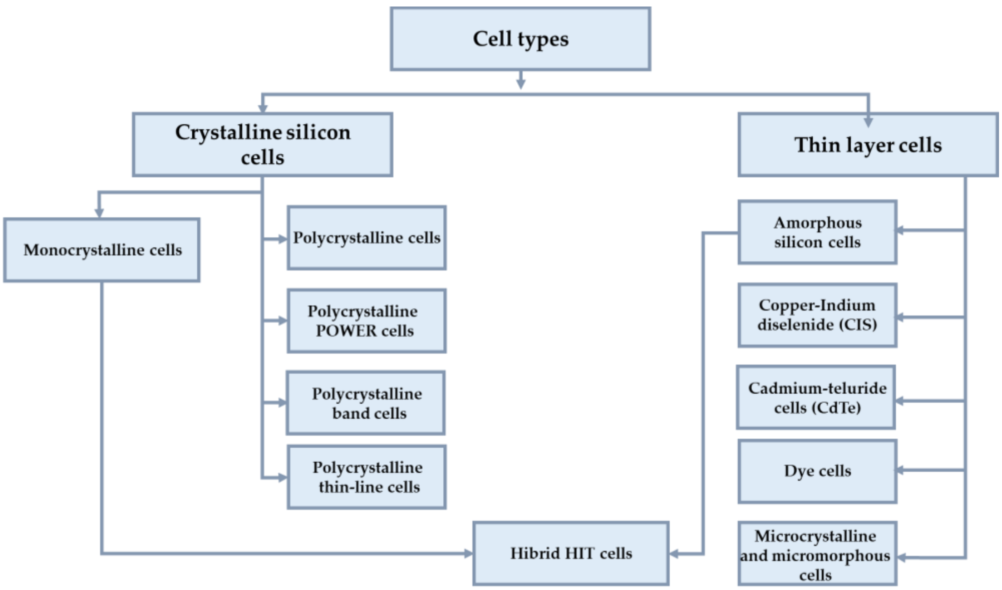

Figure 4.4.1. PV cell types [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

The thin layer cells usually have a lower manufacturing cost due to the lower amount of energy required for their production and the materials are less expensive for them. The most common thin layer cell type is the amorphous silicon cell, however Copper-Indium diselenide (CIS) and Cadmium-teluride (CdTe) is also used in thin layer cells. The thin layer cells can be made in nearly any shape, however they are usually produced in stripes, with an approximately 0.5-2.0 cm width. While they are cheaper than the crystalline silicon cells, they have a significantly lower (6-8%) efficiency.

The production process of the mono- and polycrystalline cells are shown on the following figure:

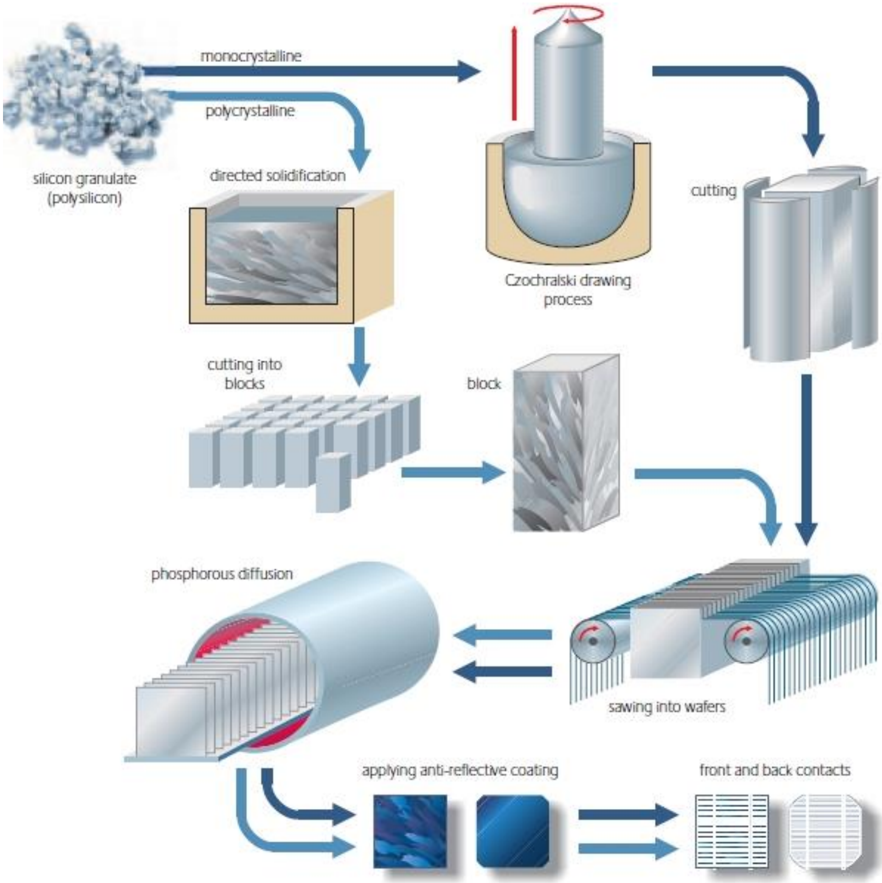

Figure 4.4.2. Manufacturing process of mono- and polycrystalline PV cells [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

The monocrystalline cells are created from a single crystal by using the so called Czochralski drawing process in which the crystallization process is directed. The formed cylinders are cut into form first and into wafers. The polycrystalline cells are made during directed solidification, that they are cut into smaller blocks and wafers. From the so called "wafer" stage the two cell types have the same finalization procedure: phosphorous diffusion, coating and electric contact installation on the front and the back of the cells. The key cell parameters are presented in Table 4.4.1.

Table 4.4.1. Cell properties of the mono- and polycrystalline cells

Monocrystalline	Polycrystalline
Several cells, but from only one crystal	Several cells, built from several crystals
Black cell colour	Blue cell colour
Efficiency ≈15-18%	Efficiency ≈ 13-16%
Relatively higher cost	Relatively lower cost
Sensitive for orientation, better utilizes direct radiation	Moderately sensitive for orientation, better utilizes diffuse radiation
Lifespan: 30 years	Lifespan: 25-30 years

OPERATIONAL PRINCIPLE

The PV cells produces electricity due to the photovoltaic effect. The silicon atom has 4 valence electrons on the outer shell. When creating the PV cells a stable crystal lattice is created in which the valence electrons make the connection between the silicon atoms (Figure 4.4.3). The electron bonds can be broken in the lattice by heat or light and there can be moving "free" electrons, however this intrinsic conductivity can't be used for electricity generation, thus impurities must be added in the crystal lattice by so called doping atoms. Usually boron and phosphorous is used, since boron has one less and phosphorous has one more valence electron on the outer layer. This means that with the boron doping a positive (p) type and with the phosphorous doping a negative (n) type of lattice can be made (Figure 4.4.4).

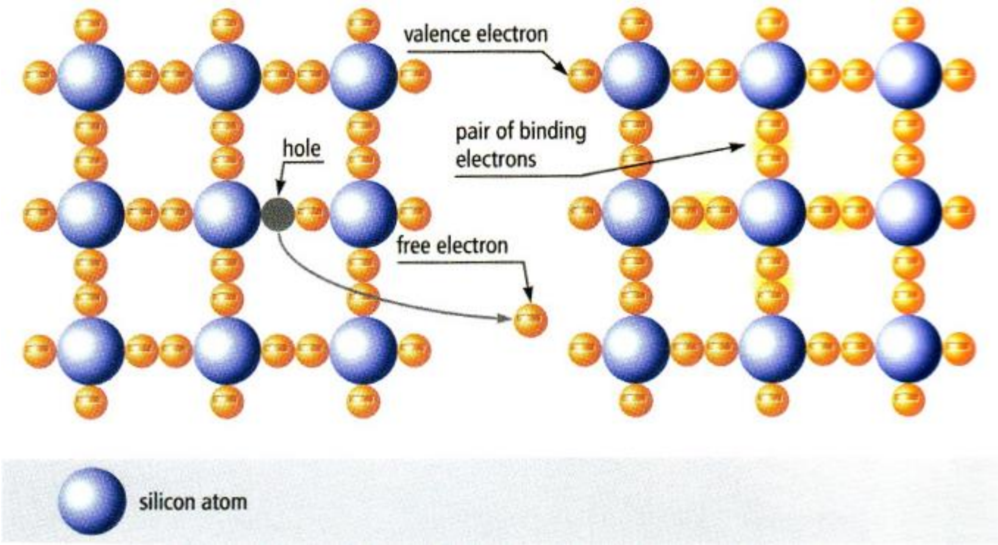

Figure 4.4.3. Silicon crystal lattice [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

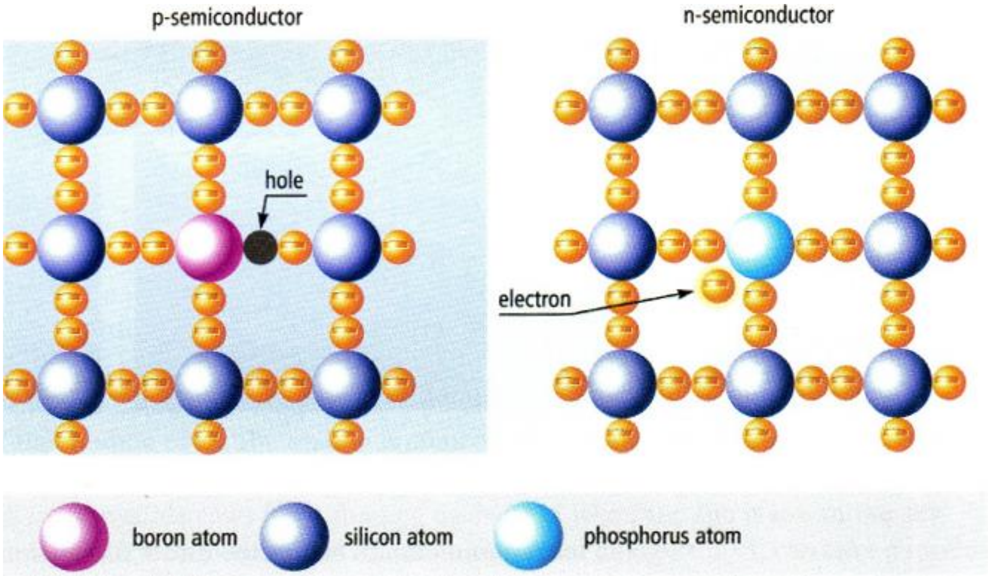

Figure 4.4.4. Silicon crystal lattice with boron (p) and phosphorous (n) doping [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

From the n-semiconductor the extra electron can move to a hole on the p-semiconductor and thus another hole is created and electrons from neighbouring silicon atoms can fill this hole, creating a hole somewhere else and this is called extrinsic conduction. The meeting of the boron and phosphorous doped layers is called a PN node, where the excess electrons can move from the n-area to the p-area and an electric field is created. Light, as a kind of catalyst, can be considered as a source of kinetic energy. It breaks the electron bonds and the released electrons can pass through the electric field, which is the so called photovoltaic effect (Figure 4.4.5).

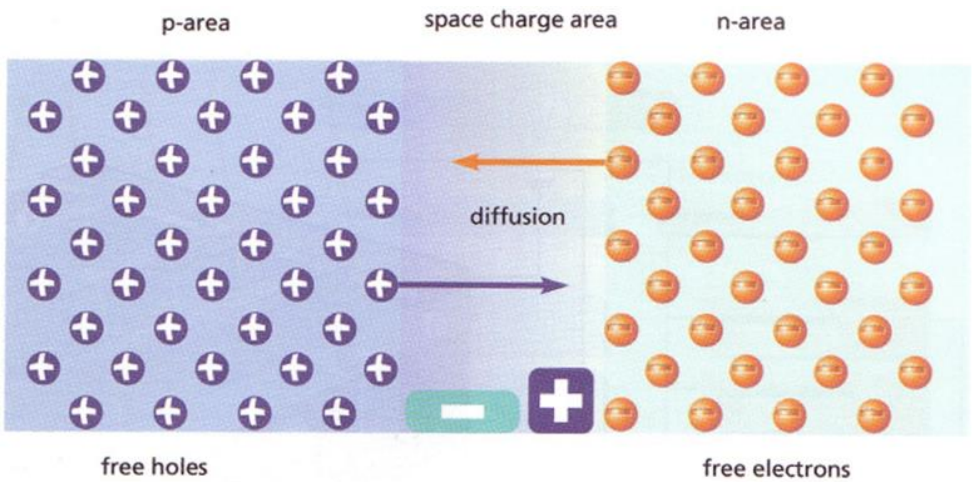

Figure 4.4.5. PN node [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

A schematic drawing of a PV cell is shown in the figure below. The top layer of the cell is the phosphorous doped n-semiconductor layer, and the bottom layer is the p-semiconductor. There is an electromagnetic field between the two layers where the free electrons move. The front and the back are connected by electrodes to ensure the flow of the generated current. On the front of the PV cell a transmissive coating can be found, while the back is usually coated by silver or aluminium.

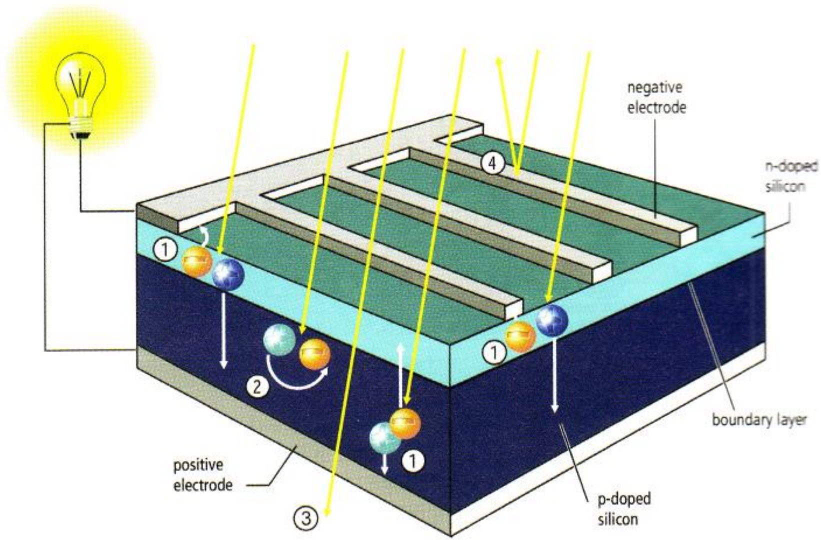

Figure 4.4.6. Schematic drawing of a PV cell [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

OPERATIONAL CHARACTERISTICS

The operational U-I characteristic of a PV cell under standard test conditions (STC) is shown on Figure 4.4.7. The STC conditions are the following:

- 25 °C cell temperature,
- 1,5 airmass,
- 1000 W/m^2 incoming radiation on the surface.

The characteristic points of the U-I curve are the short circuit current (I_{SC}), open circuit voltage (U_{OC}) and the current (I_{MPP}) and voltage (U_{MPP}) at the maximal power point (MPP). The power output of a PV cell is calculated as the product of the current and voltage ($P=U \cdot I$). The goal of the PV cell operation is to have the production at the MPP point.

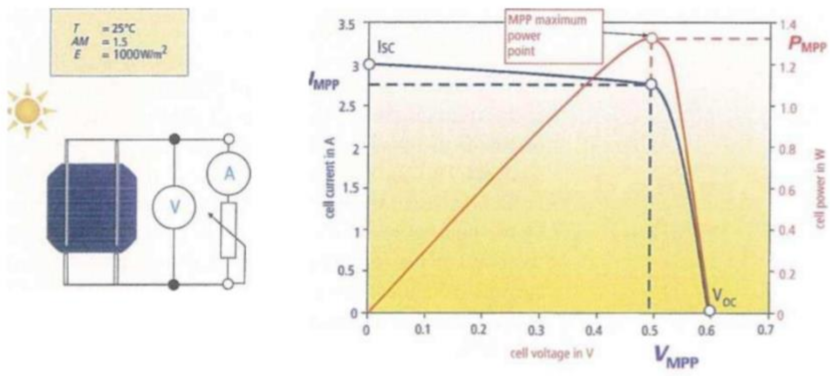

Figure 4.4.7. U-I characteristic of a PV cell [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

The quality of the PV cell can be characterised by the fill factor (FF), which is the ration of the MPP power output, and the theoretically maximal output calculated as a product of the I_{SC} and U_{OC} as shown in the figure below. The closer the value of the FF to 1 the better the quality of the PV cell is.

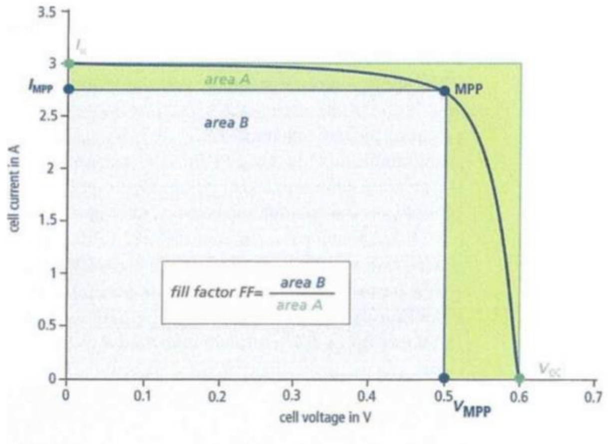

Figure 4.4.8. Fill factor of a PV cell [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

The PV modules are made up of several PV cells thus the connection of the PV cells can be in series and in parallel. The U-I characteristics of the connected PV cells can be seen in Figure 4.4.9 for the series connection and in Figure 4.4.10 for the parallel connection. In case of series connection, the voltage of the cells adds up and the current stays at the same value, while in case of parallel connection the generated current adds up and the voltage stays the same. The connection of the PV cells is very similar to that of the pumps in hydraulic systems, where the same principle can be applied, but for the pressure raise and the volume flow rate.

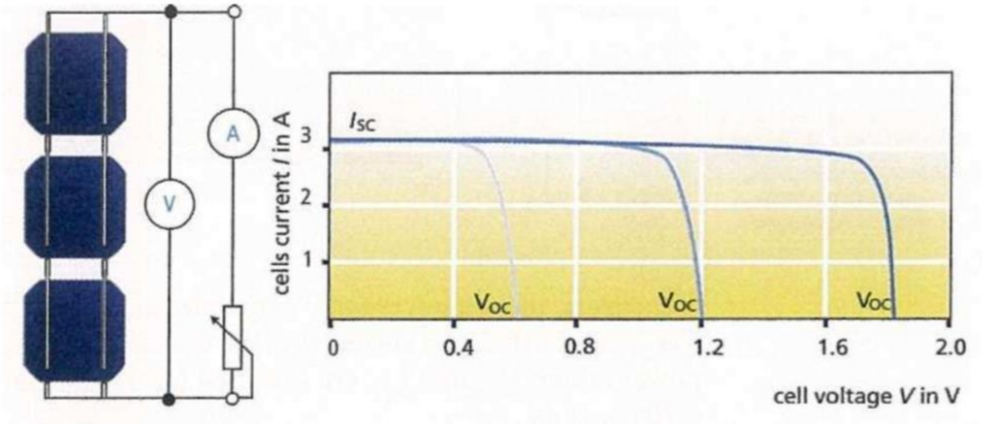

Figure 4.4.9. U-I characteristic of PV cells connected in series [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

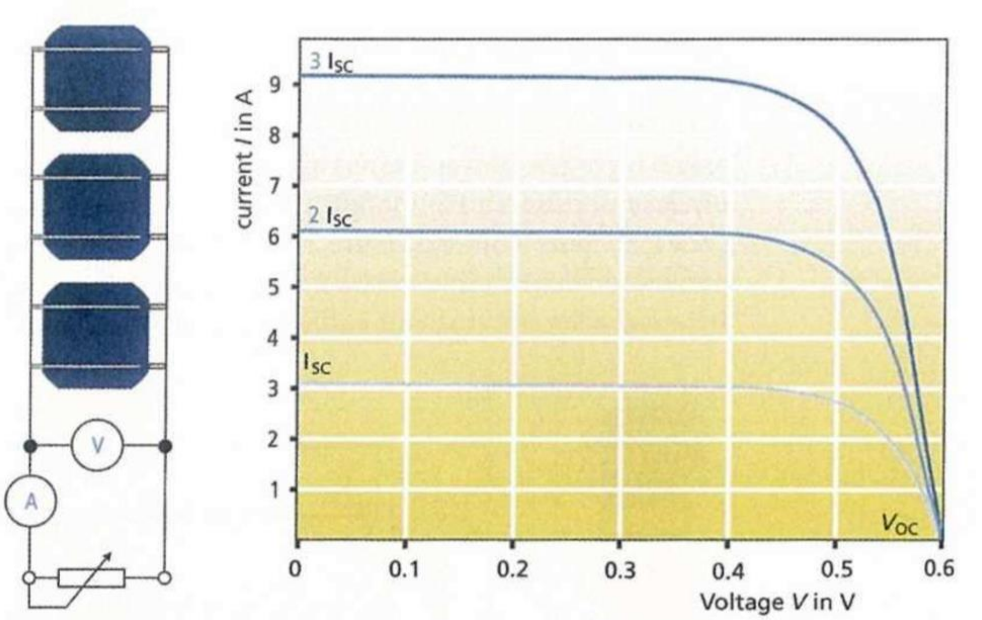

Figure 4.4.10. U-I characteristic of PV cells connected parallel [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

The characteristic of the PV cells is changing with different meteorological conditions. The two main parameters also given in the STC are the incident solar radiation intensity and the cell temperature. On Figure 4.4.11 the effect of the radiation intensity is presented. By the decreasing solar radiation, the generated current drops significantly, however the U_{MPP} value only changes in a smaller range. Figure 4.4.12 shows the effect of the different cell temperatures. On the figure the cell temperature difference ϑ is shown, where the 0 °C corresponds to the 25 °C cell temperature. It is visible that by the increasing cell temperature the U_{MPP} voltage drops significantly, while the generated current only changes in a small range. It is also worth mentioning, that at lower cell temperatures it is possible to have higher power output than the nominal rated power of the cell.

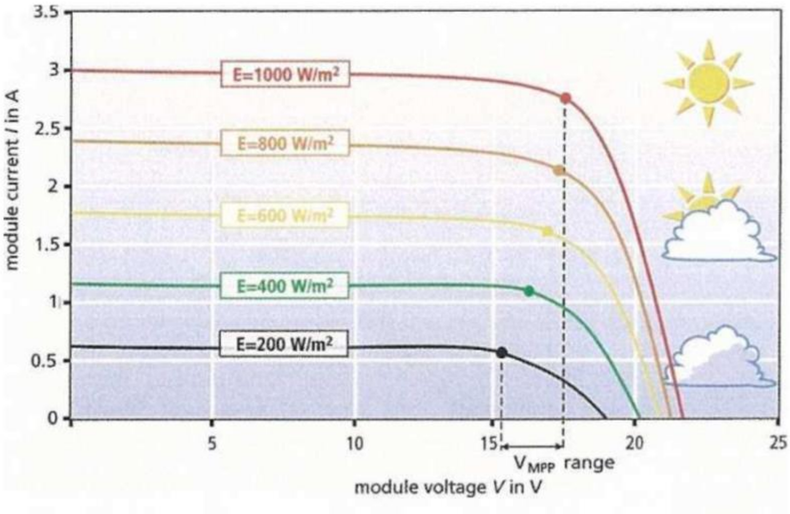

Figure 4.4.11. U-I characteristic of PV cells under different radiation intensity [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

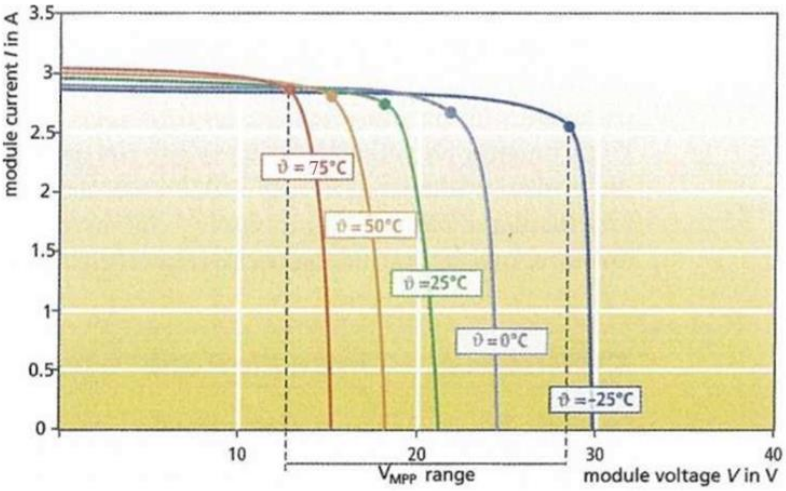

Figure 4.4.12. U-I characteristic of PV cells with different cell temperatures [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

The PV cells are sensitive for shadowing, their power output can be significantly reduced by shadowing. As an example, let's assume that there is a solar PV module with 36 PV cells connected in series (Figure 4.4.13). The current generated by the PV cells flows in the circuit and supplies the electric load (R). In case of a shadow is cast on one of the cells (e.g., a leaf falls on the PV module) the PV cell will not generate any more current and will become an electric load consuming the produced current from other cells and will start to dissipate heat (Figure 4.4.14). Through the heat dissipation the cell temperature will rise significantly and a thus a “hot spot” develops, which can lead to cell damage. The largest current that can flow is the short-circuit current. To reduce the effect of shading by-pass diodes can be added to the PV modules (Figure 4.4.15). The by-pass diode ensures, that in case of a shaded cell there can be cells that are not affected by the shaded cell and can operate under normal conditions. The effect of the by-pass diode is presented in Figure 4.4.16.

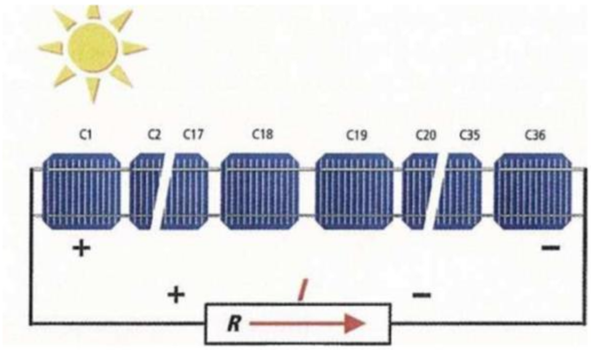

Figure 4.4.13. Operation of a shadowless PV cell series [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

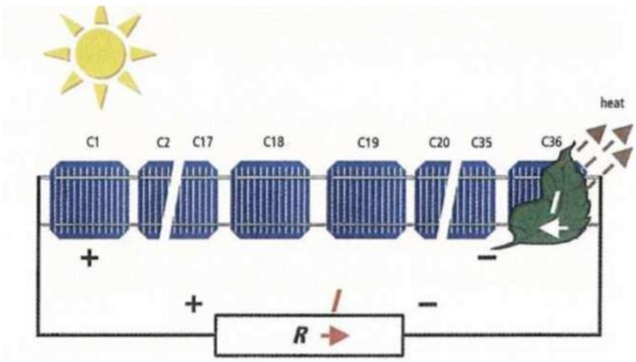

Figure 4.4.14. Operation of a shadowless PV cell series [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

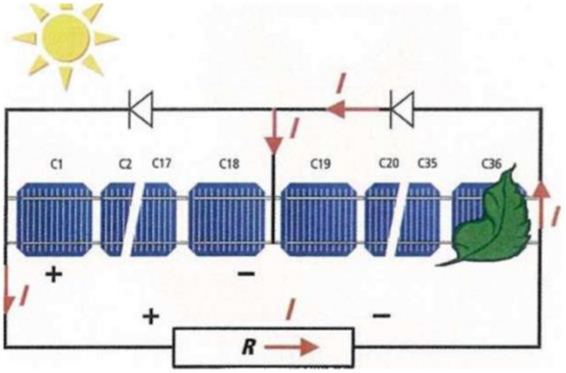

Figure 4.4.15. By-pass diode in a PV module [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

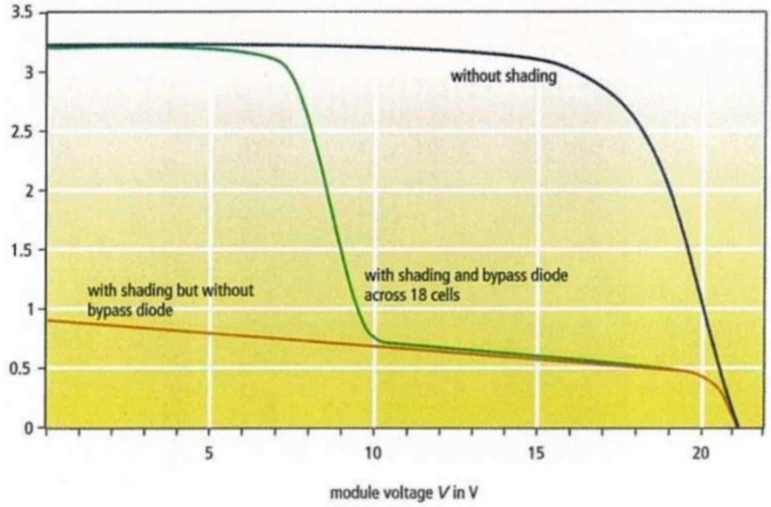

Figure 4.4.16. U-I characteristic in case of a shaded PV cell with and without by-pass diode [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

The connection of PV modules is very similar to the connection of PV cells, in case of series connection the voltage is added up and in case of parallel connection the current is added up. In practice the PV modules are connected in both series and parallel to each other and the characteristic U-I curve can be determined by applying the rules of the purely series and parallel connections (Figure 4.4.17).

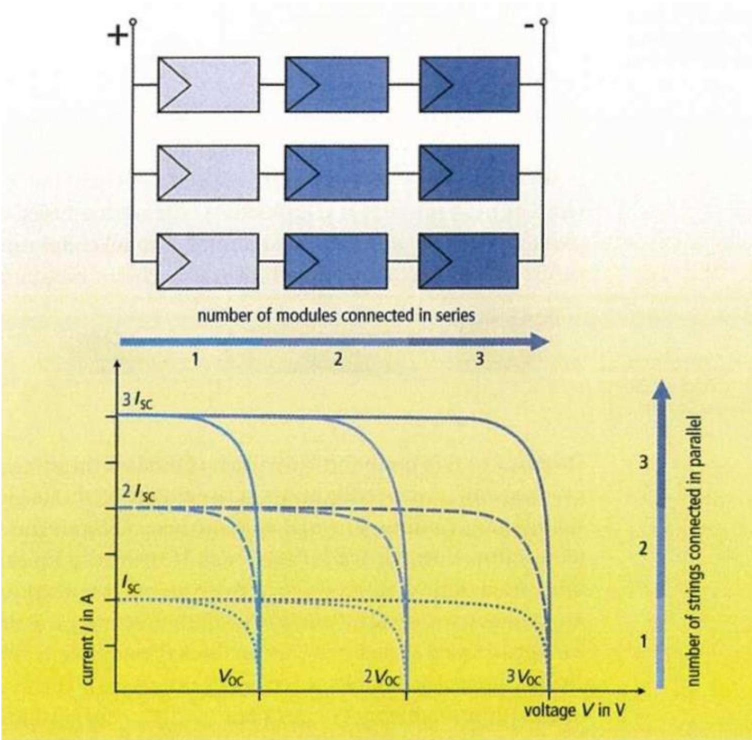

Figure 4.4.17. U-I characteristic of connected PV modules[Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

PV SYSTEM TYPES

In practice there are two main PV system types: the grid connected and the stand-alone systems. The stand-alone systems have three subcategories as shown in Figure 4.4.18: without storage, with storage and hybrid systems. The stand-alone systems without storage can only provide electricity when the PV modules are producing electricity. When storage is added to the stand-alone systems the users can have access to electricity outside of the PV production times, however storage capacity must be added to the system mostly in forms of batteries, which have only limited capacity and usually are very expensive. In case of hybrid systems other electricity generators are added to the system, which can complement the PV production. In case of grid connected PV systems the electric grid behaves as a “limitless” electricity storage as the produced electricity can be fed to the grid via a two-way electricity meter.

The main PV system elements for stand-alone and grid connected systems are shown in Figure 4.4.19. The stand-alone systems with battery storage can have a DC load before the battery, so a charge controller can provide protection for the batteries, so the charging is not too fast, which can decrease the lifetime of the battery. The direct current needs to be converted to alternating current for most applications, thus an inverter is required in the PV system, which converts DC to AC. In case of grid connected systems there is usually no battery storage due to its high cost, only the electric grid is used as storage. In this case a two-way meter is required which measures the electricity fed to the grid and also the electricity received “back” from the grid.

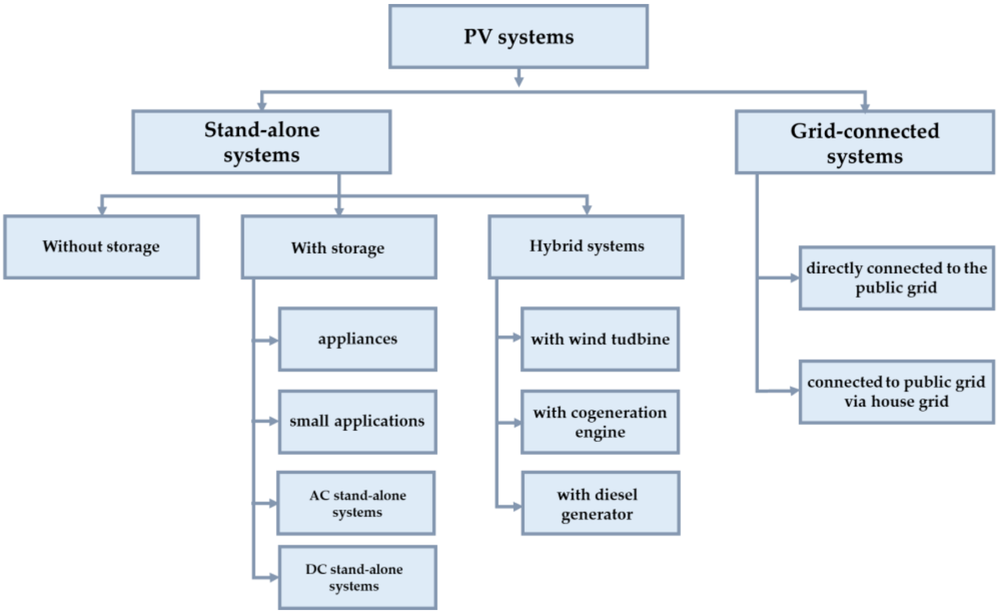

Figure 4.4.18. PV system types [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

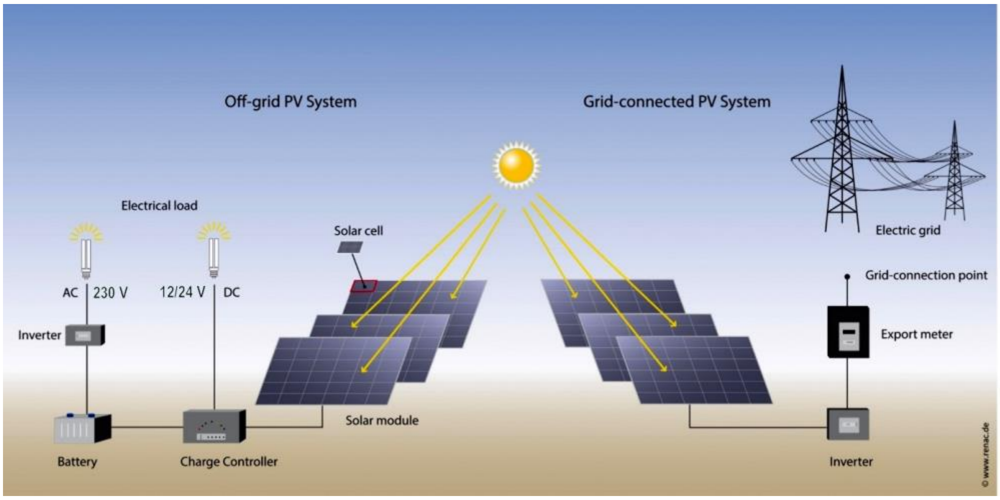

Figure 4.4.19. PV system elements of stand-alone and grid connected systems [www.renac.de]

The PV arrays can be connected in different systems depending on the inverter, in the following section the basic types are introduced:

Table 4.4.2. PV system types based on the inverter connections

System type	Advantages	Disadvantages
Low voltage system (U<120V)	relatively low sensitivity for shading	high current, bigger losses, bigger cables
Higher voltage system (U>120V)	lower current and losses	sensitive for shading
Master-Slave concept	better performance for bigger arrays	higher investment cost
String concept	solar modules are divided into strings so they can operate better	only panels with the same orientation, tilt and shading can be connected to the same string

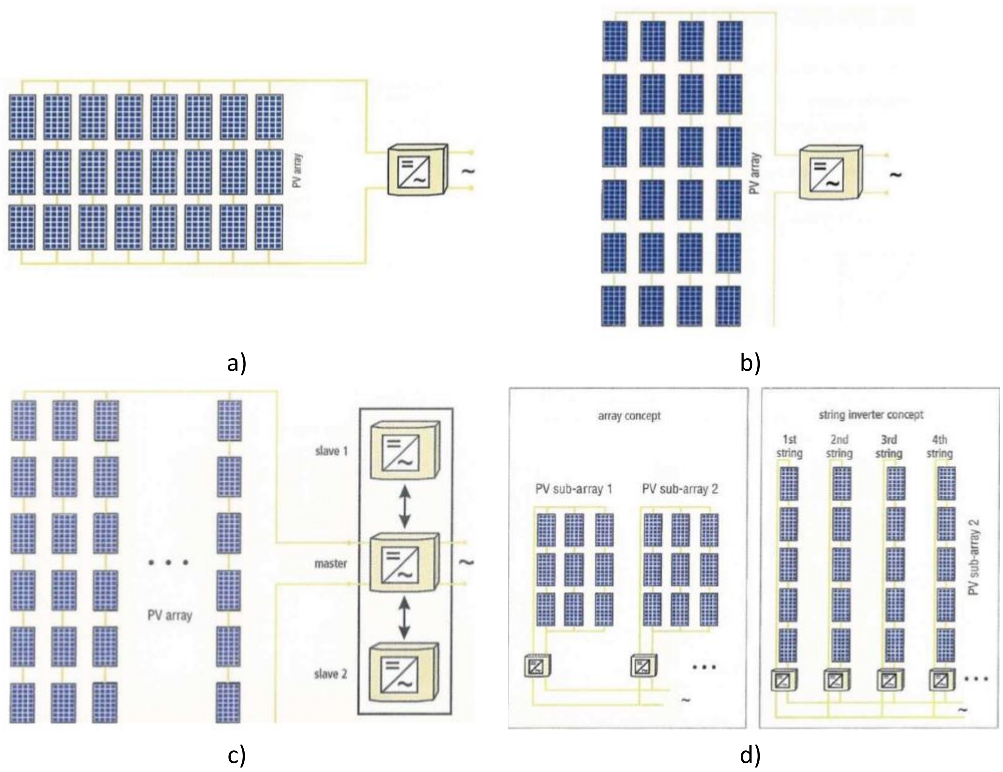

Figure 4.4.20. PV system types based on the inverter connections – a) low voltage; b) high voltage; c) master-slave; d) string concept [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

MOUNTING OPTIONS ON BUILDINGS

The PV modules can be mounted on buildings in different ways depending on the building layout and orientation. The PV modules can be mounted on the roof (pitched of flat) of the building, which can be either fixed to the roof or can be roof integrated. There is also a possibility to mount the PV modules on the façade of the building either in front of the façade or as a façade element. The PV modules can be also used for shading the glazing of the building (e.g., as glass roof or as a canopy/shutter). The last option for adding PV modules to a building is to use the field next to the building for PV placement.

In case of installing the PV modules on a pitched roof railings must be added to the roof Figure 4.4.21. The most common is the horizontal railing, where the modules are laid vertically and clamped at four points to the rails. The distance of the rails is determined by the module types and the tiling on the roof. In case of vertical railings, the modules are placed in horizontal direction, which can be more advantageous in case of shading, however the placement of the rails is limited by the roof structure – e.g., the placement of the rafters. Cross railing shall be used if the roof structure does not provide sufficient fixing points. In case of larger systems there is an option for group assembly, where the modules are clamped together on the ground and fixed on the railing in groups.

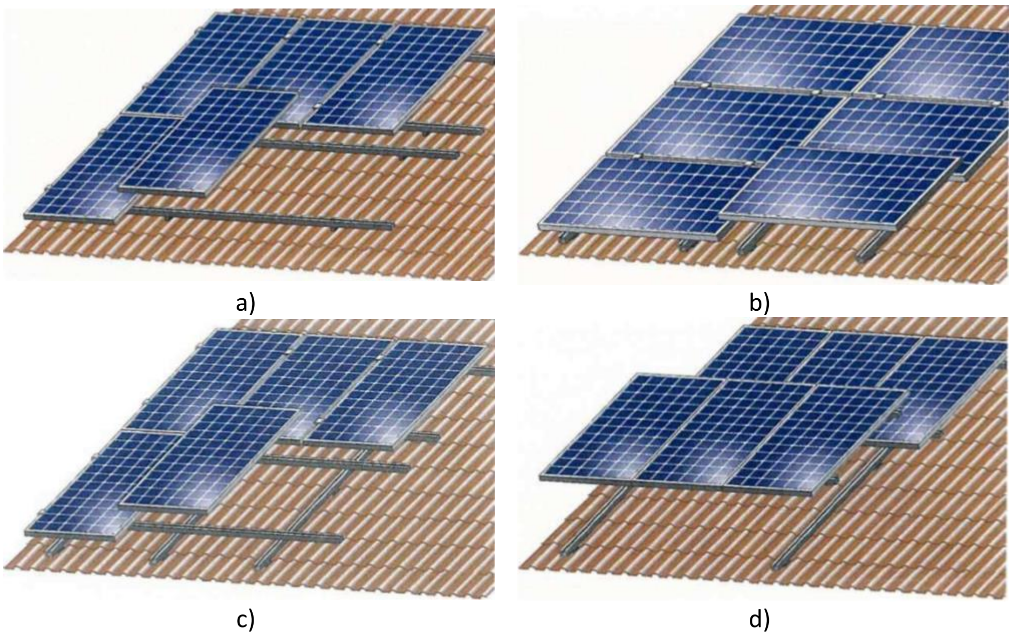

Figure 4.4.21. PV module mounting options on pitched roofs – a) horizontal railing; b) vertical railing; c) cross-railing; d) group assembly [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

For flat roofs the PV modules are usually placed in a free-standing position, thus the effect of the wind must be considered as well (Figure 4.4.22). The usable surface of the flat rood is limited by the possible shadowing objects on the rood and space should be left on the edges of the roof (Figure 4.4.23).

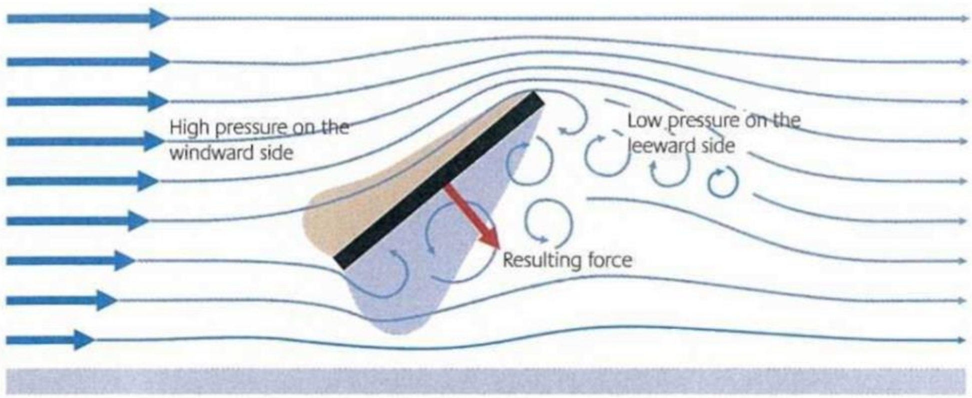

Figure 4.4.22. Wind pressure on a free-standing PV module [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

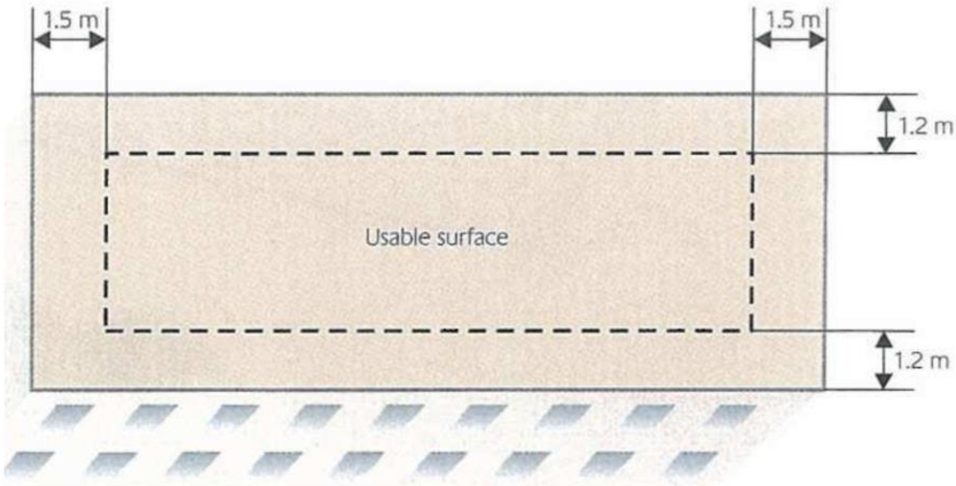

Figure 4.4.23. Usable roof space on a flat roof for PV modules [Planning & Installing Photovoltaic Systems, 2nd ed., Earthscan Ltd, London, 2008]

PV SYSTEM ENERGY PRODUCTION

PV system's electricity production also depends on the modules' orientation and tilt angle. The operation of PV modules has certain characteristics depending on the orientation. Modules placed horizontally or facing to towards the Equator have a production pattern which follows the position of the Sun, having its peak at noon. While modules facing East have the peak of the production in the morning and West facing modules have it in the afternoon. The yearly energy output of the PV modules can be calculated using the freely available PVGIS software (Figure 4.4.24). The program requires the basic parameters of the PV system: the location to determine the meteorological database to be used. The PV technology to determine the cell efficiency. The installed peak power and the system losses. Also, the tilt and orientation of the system shall be given as input, while the program also has an option to optimise the orientation and tilt angle. The horizon of the site can also be added in the form of a "csv" file format. Tracking PV systems can also be modelled, in this case the tracking mounting options must be added to the inputs (vertical axis, inclined axis or two axis). For off-grid applications (stand-alone systems) the battery and consumption characteristics must be added for the calculations.

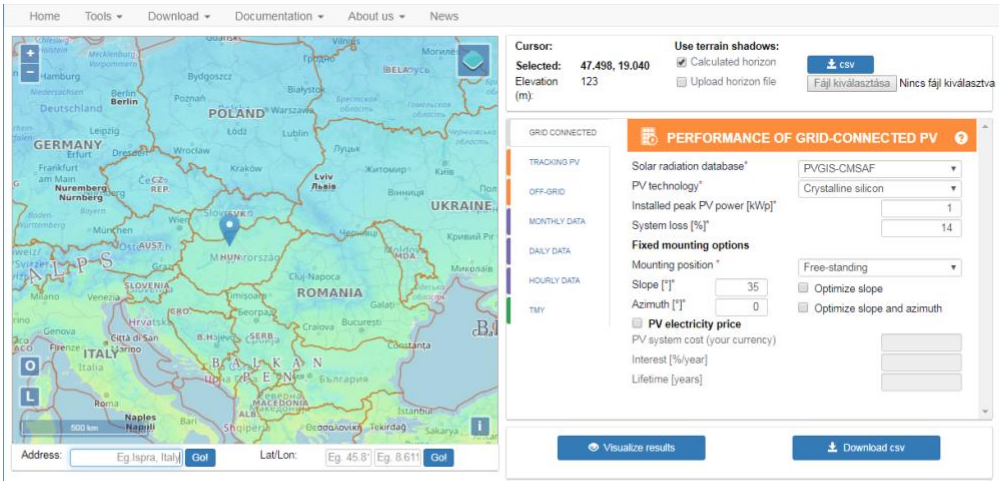

Figure 4.4.24. PVGIS program interface [https://re.jrc.ec.europa.eu/pvg_tools/en/]

SOLAR PV-T

Solar PV-T systems are a combination of PV systems and solar collectors. They can produce both electricity and heat in a single unit, which allows to save on utilisable surface area. Also, another benefit of the PV-T systems is that the additional heat removal from the PV cells increases their efficiency.

SYSTEM TYPES

PV-T systems can be categorised by their heat transfer medium and the build of the PV-T modules. The main PV-T types are the following:

- liquid-cooled uncovered PV-T flat-plate collectors,
- liquid-cooled covered PV-T flat-plate collectors,
- air-cooled PV-T flat-plate collectors,
- concentrating PV-T systems.

Figure 4.4.25 shows the section of an uncovered PV-T collector. From the figure it is visible that in this case the PV cells have a protective cover against the weather, and they are directly connected to the pipes on their back. This system allows a direct heat transfer and thus heat removal from the PV cells to the fluid. Figure 4.4.26 shows a glazed collector, where an additional air gap is present to improve the heat insulation of the module, thus higher temperatures can be reached than with the uncovered modules. The thermal output curves for different liquid cooled PV-T systems are presented in Figure 4.4.27.

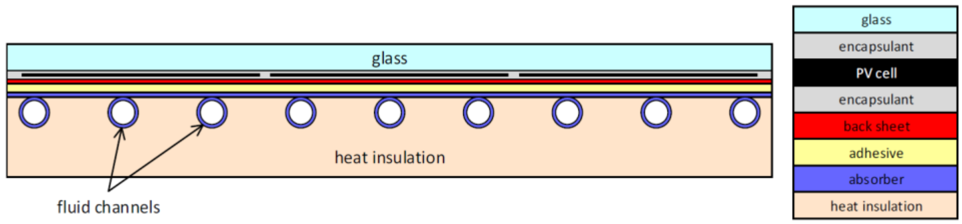

Figure 4.4.25. Schematic of an uncovered PV-T collector [*Energy systems with photovoltaic-thermal solar collectors*]

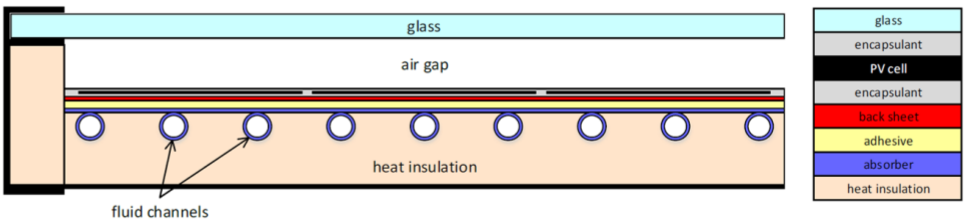

Figure 4.4.26. Schematic of a covered PV-T collector [*Energy systems with photovoltaic-thermal solar collectors*]

Due to the higher thermal losses for the uncovered modules the heat output is lower, however there is a lower risk for the stagnation period, since the temperature in the pipes usually can't go over 120 °C, thus the gasification of the liquid in the pipes is not occurring, so the system is not ruined. For the covered modules the stagnation periods have to be avoided in order to prolong the safe operation of the modules. However, due to the higher temperatures the covered modules have more flexibility for the thermal applications.

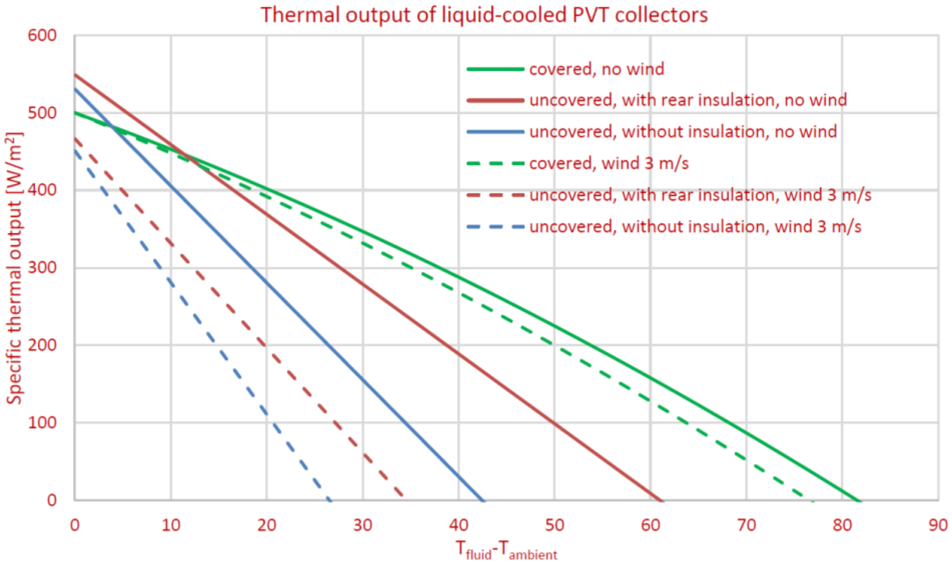

Figure 4.4.27. Thermal output of typical liquid-cooled PVT flat-plate collectors at MPP [Energy systems with photovoltaic-thermal solar collectors]

Air-cooled PV-T collectors use air as the heat transfer medium instead of liquid. Similarly, to the liquid cooled PV-T collectors there are both glazed and unglazed types as well. They are in general very similar to solar wall systems, the main difference is that the air cooled PV-T collectors also produce electricity. The uncovered types have higher heat losses than the covered types, thus the applicability of the uncovered systems are limited in regards of the heat utilisation, since only lower temperatures can be reached. The main advantage of the air-cooled PV-T collectors compared to the liquid cooled counterparts is the simplicity of the construction, there is no need to install piping and the stagnation of the heat transfer medium is harmless for the system. The main drawback of the air-cooled systems is the significantly lower heat capacity of the air, which means there is a need for significantly higher volume flows and thus duct cross sections.

Concentrating PV-T systems are still under research. In this case the high efficiency PV cells are placed in the receiver of the concentrating system. The concentrating system also requires a tracking mechanism to maximise the heat output of the modules, which can reach high temperatures, that are suitable also for industrial purposes.

The electrical efficiency can be calculated by correcting the STC efficiency (η_{STC}) of the PV-T module by the radiation (G [W/m^2]) and the heat transfer liquid temperature (ϑ_m [°C])

$$\eta_{el}^{MPP} = \eta_{STC}^{MPP} \cdot \left(1 - 0.04 \cdot \ln\left(\frac{G}{1000}\right) + \gamma_{STC}^{MPP} \cdot (\vartheta_m - 25)\right) \qquad 1$$

From the module's electrical efficiency the electrical output of the system can be calculated:

$$P_{el}^{MPP} = \eta_{el}^{MPP} \cdot G \cdot A \qquad 2$$

The combined heat and electricity production of different liquid cooled PV-T module types are shown on the following figure:

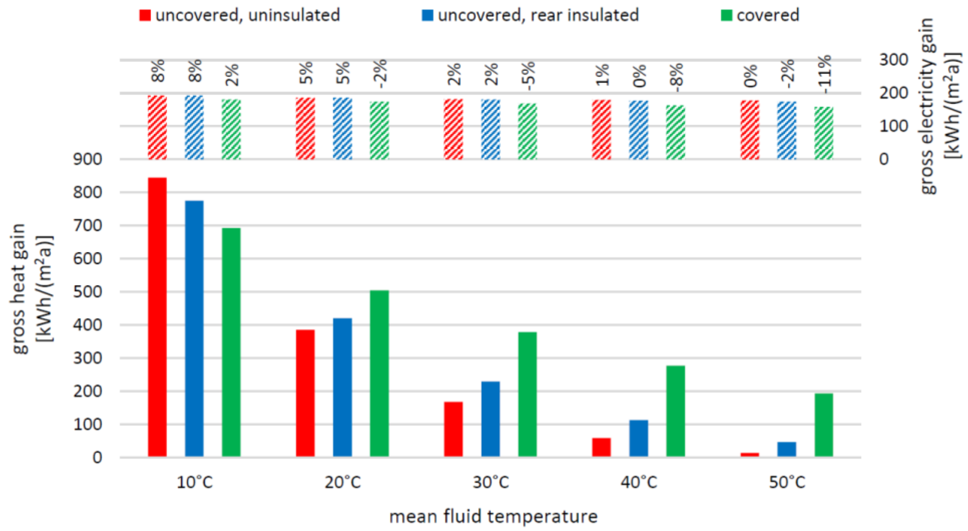

Figure 4.4.28. Annual gross heat gain (solid bars) and gross DC electricity gain (shaded bars) for various liquid-cooled PV-T collector types related to the gross collector surface area [Energy systems with photovoltaic-thermal solar collectors]

Depending on the module types and the mean fluid temperature the uncovered collector types (without or with rear insulation) have a lower heat output in case of fluid temperatures above 20 °C. However, the electric gains have an opposite trend, the uncovered collectors increase the electric output of the PV cells.

WIND TURBINES

Wind turbines are used to utilise the kinetic energy of the wind. Depending on the size the electrical output of the wind turbines can vary greatly depending on the size of the wind turbine blades, which can reach over 160 m in diameter. The development of the wind turbine sizes is shown in the following figure:

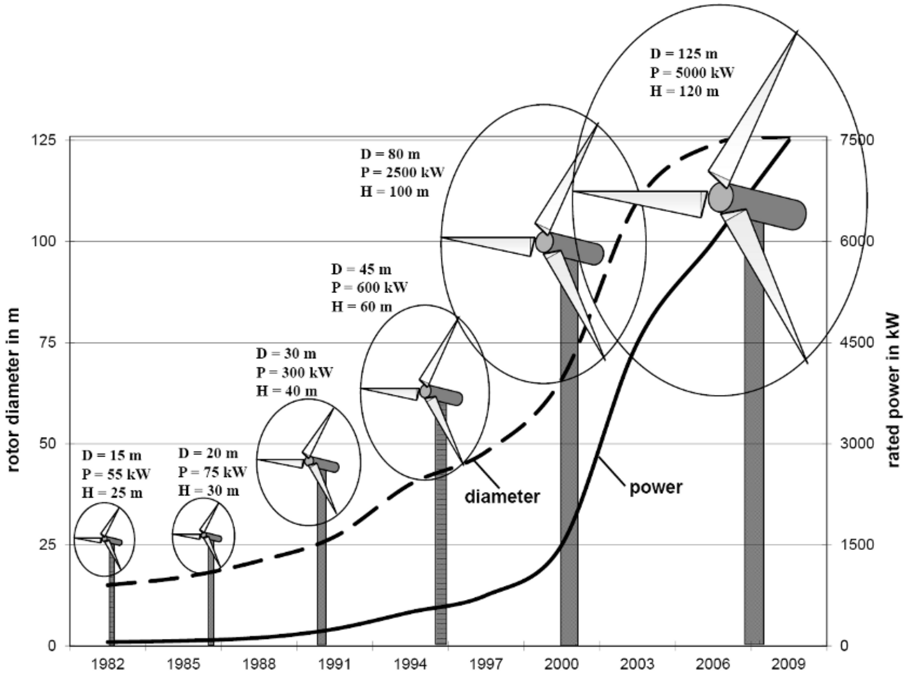

Figure 4.4.29. Wind turbine size development over the years [Robert Gasch & Jochen Twele: Wind Power Plants: Fundamentals, Design, Construction and Operation Second Edition, Springer, 2012]

The kinetic energy in the wind can be calculated as a function of the density of the air and the windspeed:

$$E_k = \frac{1}{2} \cdot \rho \cdot v^2 \qquad 3$$

where:

E_k is the kinetic energy [J]
ρ is the density of the air [kg/m³]
v is the windspeed [m/s]

The density of the air is dependent on the temperature and the humidity content of the air. The temperature dependence is shown in the following table:

Temperature [C°]	**-25**	**-20**	**-15**	**-10**	**-5**	**0**	**+5**
Density [kg/m^3]	1.423	1.395	1.368	1.342	1.317	1.292	1.269

Temperature [C°]	**+10**	**+15**	**+20**	**+25**	**+30**	**+35**	**+40**
Density [kg/m³]	1.247	1.225	1.204	1.184	1.165	1.146	1.127

From the table it is visible, that with the decreasing temperature the density of the air increases, thus in colder regions the kinetic energy of the wind at the same windspeed is higher, which is the reason for the increasing wind energy utilisation ambitions in colder regions.

To determine the energy flowing through an area the following equation can be used:

$$P = \left(\frac{1}{2}\rho v^2\right) \cdot v \cdot A = \frac{1}{2}\rho v^3 \cdot A \qquad 4$$

In case of wind turbines only a fraction of the kinetic energy of the wind can be utilised, which means, that the air can't be "stopped" by the blades of the wind turbines. As a rule of thumb, the optimal output can be reached if the windspeed at the rotor plane is 2/3 of the undisturbed air's speed and the air speed downstream of the rotor is 1/3 of the undisturbed air speed. This is shown on Figure 4.4.30 as well.

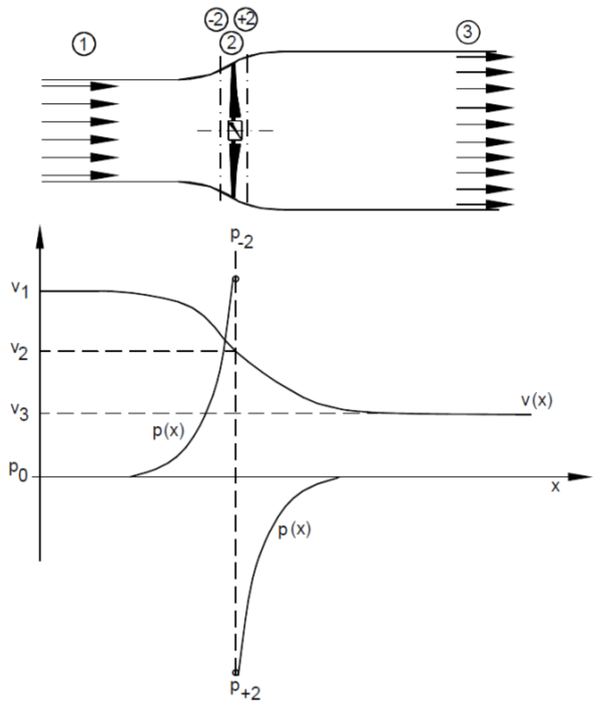

Figure 4.4.30. Development of velocity and static pressure p along the stream tube [Robert Gasch & Jochen Twele: Wind Power Plants: Fundamentals, Design, Construction and Operation Second Edition, Springer, 2012]

The output of the wind turbine also depends on the characteristics of the rotor blades, however the theoretical maximum of the efficiency can be calculated as a function of the power of the wind at the turbine and before the turbine and is approximately 59%.

ELECTRICITY GENERATION

For wind turbines the electricity generation is based on three-phase alternators, which produce an alternating current (AC), which is the opposite of the PV systems, which produce direct current (DC). However, this means, that the rotor of the wind turbine should rotate at a set pace, which is almost possible, usually they rotate at the desired frequency (50 Hz in Europe or 60 HZ in the USA) at a wind speed of approximately 8 m/s. Due to the technical advancement of the converter technology the wind turbines can operate at various wind speeds. For wind turbines there are two characteristic windspeeds: the cut-in and the cut-out. At the cut-in windspeed the wind turbine starts to generate electricity and with increasing windspeed the electric output grows up to the nominal windspeed, above which the power output is constant until the cut-out speed, where the production of the wind turbine must be stopped to prevent mechanical damage. A characteristic wind turbine power output is presented below:

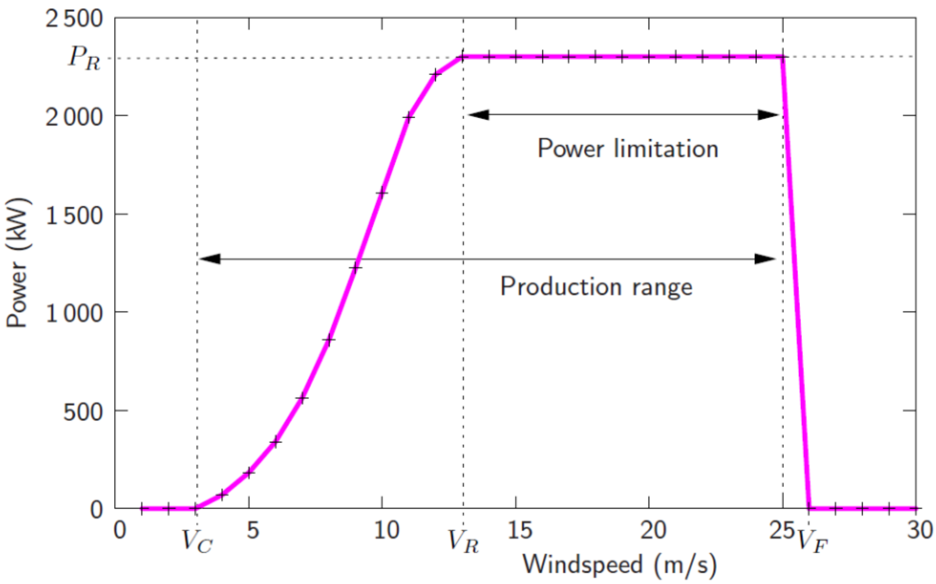

Figure 4.4.31. Nordex Wind Turbine Power Curve

An operational wind turbine's output is shown in Figure 4.4.32. From the diagram it is visible that the theoretical and measured power curves are different, the measured one being slightly lower than the theoretical. The difference becomes bigger with bigger windspeeds, including high fluctuations over 14 m/s windspeed. The windspeed histogram is also presented on the figure, from which it is clearly visible, that for most part the windspeed is in the utilisable range.

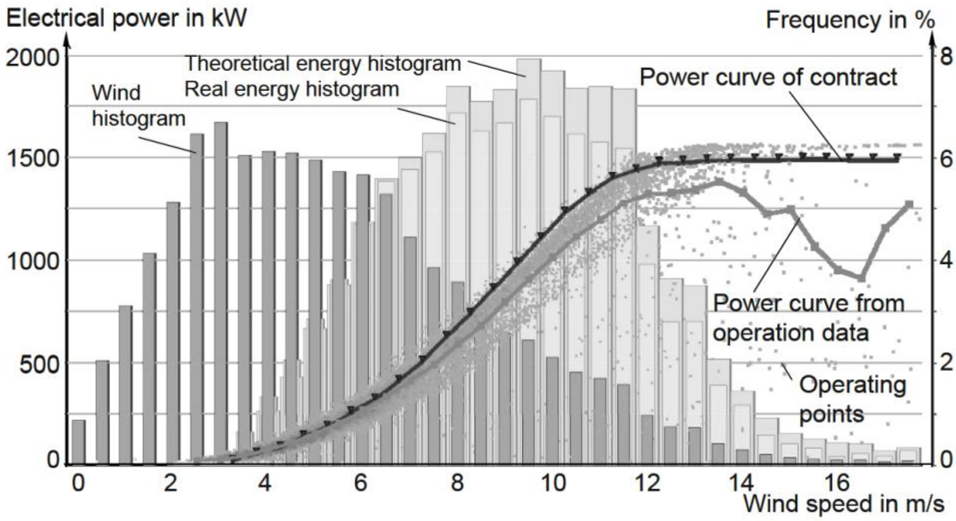

Figure 4.4.32. Development of velocity and static pressure p along the stream tube [Robert Gasch & Jochen Twele: Wind Power Plants: Fundamentals, Design, Construction and Operation Second Edition, Springer, 2012]

BUILDING LEVEL WIND TURBINE INSTALLATION OPTIONS

For buildings there are three main possibilities to install wind turbine systems, which are the following:

- **BIWT – Building Integrated Wind Turbines:** the wind turbines are attached to the building but are not necessarily connected to them.
- **BMWT – Building Mounted Wind Turbines:** the wind turbines are connected to the structure of the building. Usually, the building has a tower shape and its geometry and structure is appropriate for installing wind turbines and to mitigate the vibration, weight and noise coming from the turbines.
- **BAWT – Building Augmented Wind Turbines:** the building is purposely used to profile and strengthen wind flow through the installed turbine. This effect can be achieved by a special roof construction which is used as a flow concentrator or the turbines are mounted on the edge of the roof.

COGENERATION

In case of cogeneration the waste heat from the electricity production plant is being used as a source of heat. In case of building the most viable solution is a gas engine fuelled by natural gas, however it can also be based on LNG, biogas, oil etc.

The produced electricity is provided by a regular generator, which utilises mechanical energy and converts it to electricity.

OPERATIONAL PRINCIPLES

In the CHP systems the key is to utilise the excess heat from the CHP engine, which is an additional by-product for the electricity generation. The heat from the cogeneration can be obtained from the following parts:

- Cooling liquid (usually water)
- Heat recovery from the exhaust

A typical CHP system can be seen in the following figure:

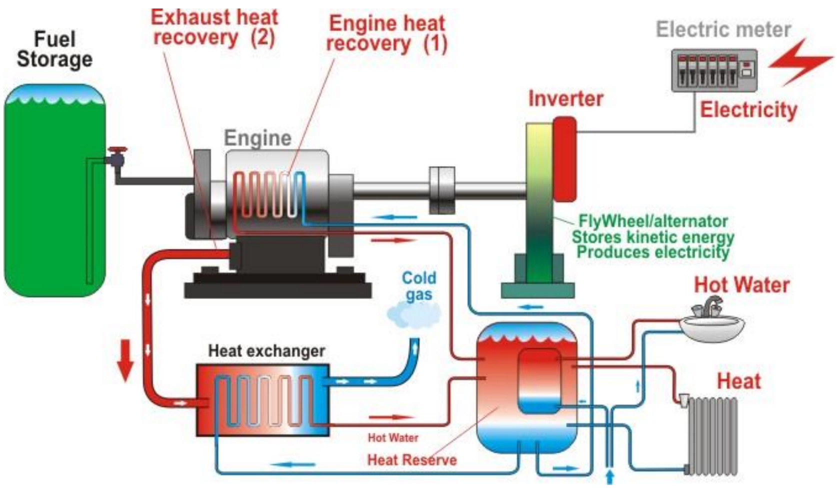

Figure 4.4.33. Schematic of a CHP system [*http://www.energiestro.com/images/us_cogeneration.jpg*]

The engine receives the fuel for combustion from a fuel tank, which is directly connected to the engine. The first part of the heat recovery is from the engine and the second is from the exhaust system, both heat removals are achieved by heat exchangers. The engine spins a generator to produce the electricity. The heat removed from the engine and exhaust can be stored in a heat storage tank, from which the heating and DHW system of the building can be supplied. The electricity can be used on-site, or it can be fed to the electricity grid via a two-way electricity meter.

The efficiency of the CHP system is higher than a traditional electricity generator's efficiency, due to the fact, that the heat removed from the CHP engine is also utilised. A simplified efficiency and primary energy comparison is show in the figure below:

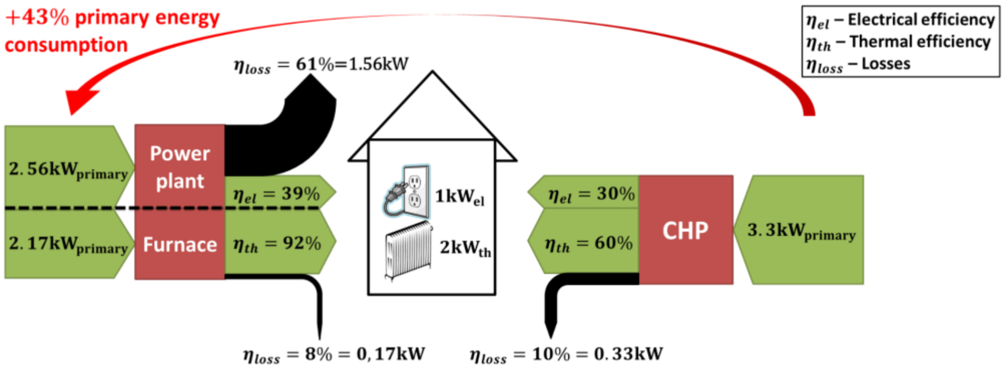

Figure 4.4.34. Efficiency and primary energy consumption comparison of a traditional and a CHP system [*https://energyeducation.ca/wiki/images/thumb/3/32/CHPefficiency.png/1200px-CHPefficiency.png*]

From Figure 4.4.34 it is visible, that to supply 1 kW electricity and 2 kW heat with traditional systems – power plant for electricity and boiler for heating – the required primary energy is approximately 4.73 kW, while in case of the CHP system it is 3.3 kW, which is 30% less energy. However, it must be noted that for the CHP system the primary target is to supply electricity to the building, thus the heat output is only a secondary benefit. While in winter it is possible to utilize the "waste heat" from the CHP system in summer it can limit the availability of the CHP engine, or it would operate only as a normal electricity generator if there is no demand for the produced heat. This issue could be mitigated by a trigeneration system, where the CHP engine apart from providing electrical and heating energy it also produces cooling energy. An example of such a system is presented in the figure below:

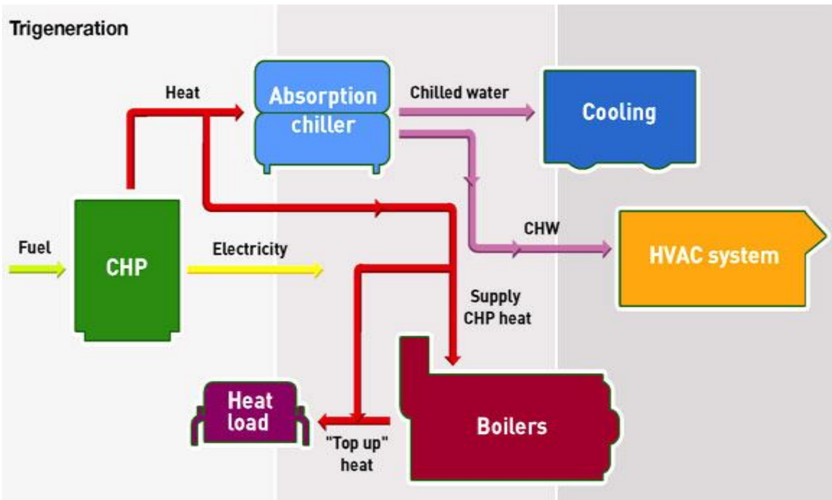

Figure 4.4.35. Trigeneration CHP system example [*https://i2.wp.com/www.cleantechloops.com/wp-content/uploads/2012/04/Trigeneration_Cycle.jpg*]

The trigeneration system has an additional loop, which includes an absorption chiller being able to provide cooling energy. The absorption chiller is fundamentally utilise heat to regenerate the unit in order to be able to provide the required cooling output. Due to the complex technology the absorption chillers are still not widespread, however their price is getting lower do to mass production.

The views and opinions expressed in this publication are the sole responsibility of the author(s) and do not necessarily reflect the views of the European Commission.

Co-funded by the Erasmus+ Programme of the European Union

MŰEGYETEM 1782 STU SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA TECHNISCHE UNIVERSITÄT KAISERSLAUTERN ENERGIAKLUB CLIMATE POLICY INSTITUTE APPLIED COMMUNICATIONS