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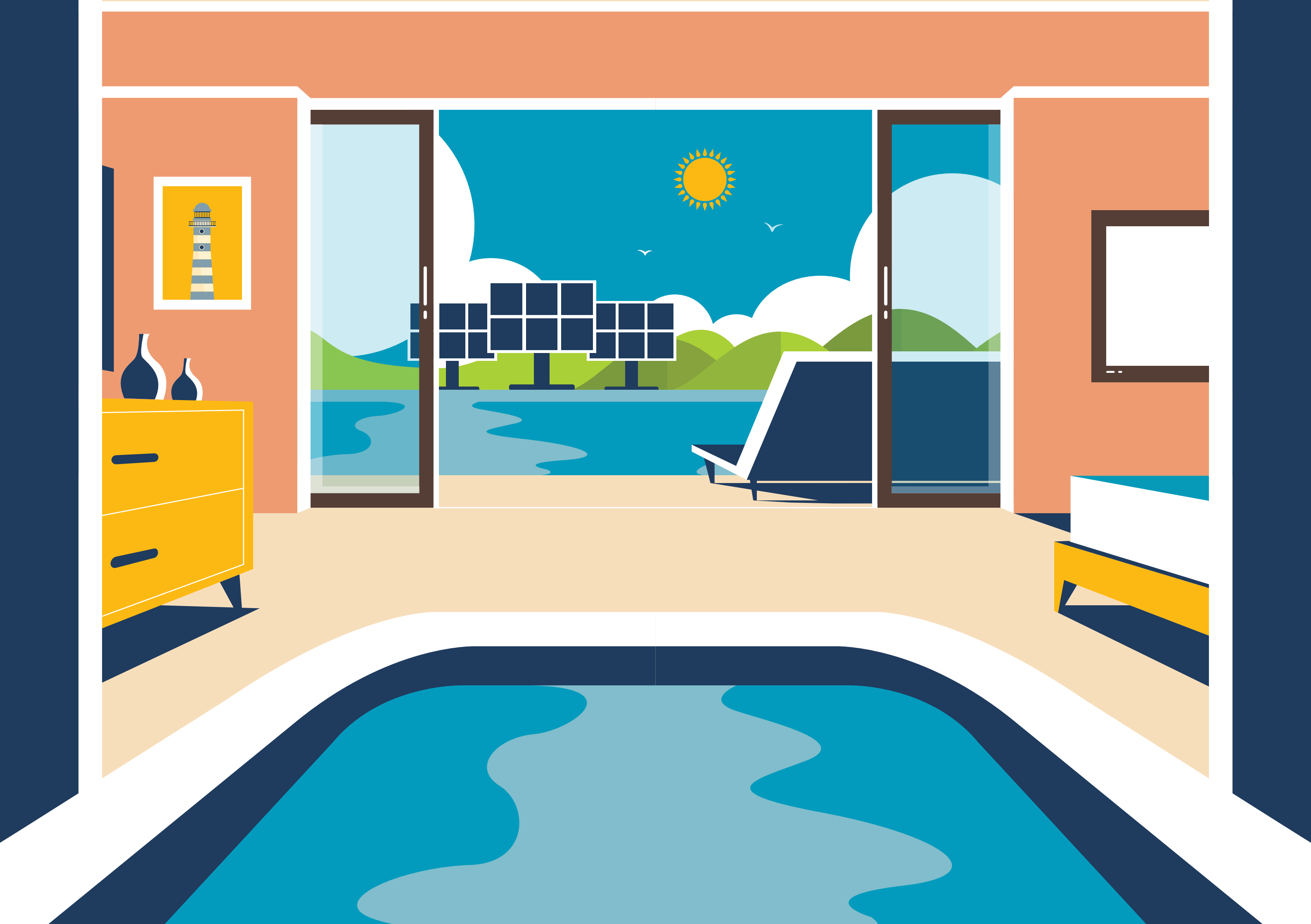
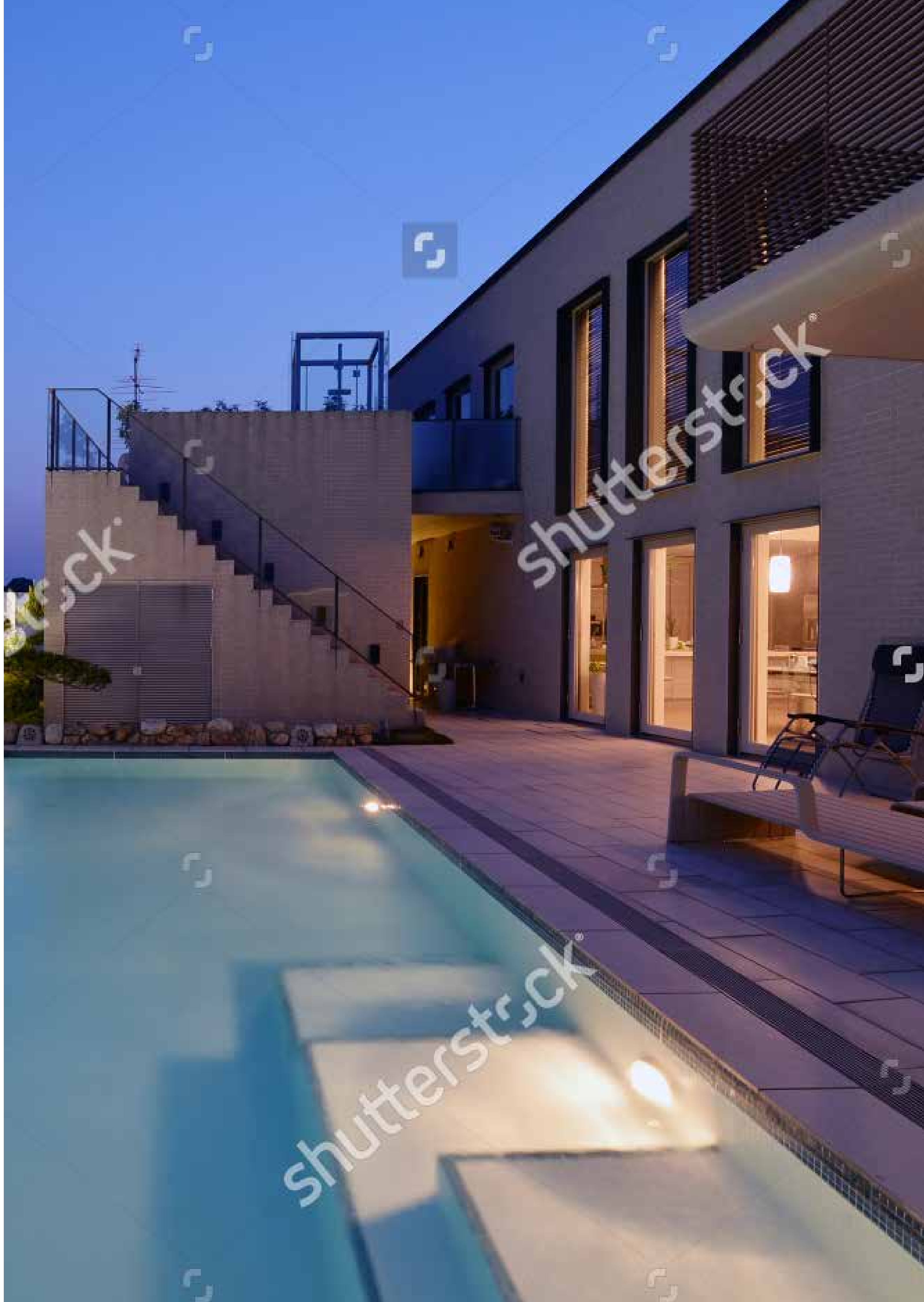
Regional Center for Renewable Energy and Energy Efficiency
المركز الإقليمي للطاقة المتجددة وكفاءة الطاقة

SOLAR PV & THERMAL APPLICATIONS FOR HOTEL SECTOR

TECHNICAL MANUAL FOR THE MENA REGION





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TITLE:

Technical Manual on Solar PV and Solar Thermal Applications for the Hotel Sector in the MENA Region

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ABOUT RCREEE

The Regional Centre for Renewable Energy and Energy Efficiency (RCREEE) is an independent intergovernmental regional organisation, which mission is to facilitate, increase and mainstream the adoption of renewable energy and energy efficiency practices in the Arab region. RCREEE teams up with regional governments and global organisations to initiate and lead clean energy policy dialogues, strategies, technologies and capacity development in order to increase Arab states' share of tomorrow's energy.
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ABOUT RE-ACTIVATE

RE-ACTIVATE is a regional project for “Promoting Employment through Renewable Energy and Energy Efficiency (RE/EE) in the Middle East and North Africa (MENA) (RE-ACTIVATE)”, funded by the Federal Ministry for Economic Cooperation and Development (BMZ) and implemented by GIZ in cooperation with RCREEE to support the national (Egypt) and regional cross-border cooperation and know-how transfer on employment promotion through RE/EE in the MENA region.

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Overview

Tourism is a key dynamic industry that has played a pivotal role in flourishing economies in the Middle East and North Africa (MENA) region over the past years. In 2015, tourism sector generated about USD 194.5 billion or 8.0% of GDP[1]. This figure is further estimated to increase to USD 3 trillion by 2020. Furthermore, job opportunities created by tourism witnessed a noticeable growth from 4.5 million in 2011 to 8 million in 2015, a double increment in just a 4-year period signals the growing importance of tourism in the region.

Moreover, not only does tourism bring economic benefits to countries, but also has remarkable social and environmental benefits. From a social point of view, tourism helps significantly to preserve traditions which might be at risk, by showcasing the unique diverse characteristics of history, culture and lifestyle[2]. This would result in strengthening the real sense of pride and identity to local communities in MENA region. In terms of environmental benefits, tourism does encourage preservation of ecosystems, and calls for proper management of natural resource in order to make destination more authentic and desirable to tourists.

Energy security in tourism industry

Based on the fact that electricity has been a central controversial concern for governments in the MENA region, energy security poses a serious challenge to the tourism industry in the region. This can be mainly attributed to the high burgeoning demand of energy in the sector that is an unsurprising fact due to the energy-intense applications such as cooling systems as well as pool and water heating, let alone the demand for lighting of indoor and outdoor facilities and other domestic electrical appliances. Such a demand is becoming increasingly difficult to meet through utility grid because of mounting deficit in power generation (mainly due to a remarkably high population growth) particularly in the net oil-importing countries such as Morocco, Tunisia and Egypt[3].

The challenge of energy security is further aggravated on account of weak or even non-existing energy infrastructure that could not provide reliable power supply to tourism destinations in both urban and remote areas. Likewise, poor management of resources and unsustainable practices have increased the magnitude of energy security problem in tourism sector. As a result, inefficient insulations and intense electricity consuming technologies have prevailed for many years now.

Energy security constitutes a profound obstacle to achieving equitable, sustainable as well as long-lasting development in the tourism sector. This is particularly true in the time of Arab Spring, 2011, when extreme power blackouts were commonplace. Ongoing political turmoil and economic stagnation further exacerbated challenge of energy security, and clearly underlined its economic importance. For example, in Egypt, a key tourist destination in the region, frequent power outages caused the number of tourists arrived to drop by 30% in 2014 alone, leading to a considerable reduction in the revenues estimated at 20% to 30%[4]. In Yemen, a country that used to be popular tourist destination, the semi-complete halt of electricity supply resulted from the ongoing instability rendered the country's tourism sector rather obsolete with no arrival at all[5]. In a nutshell, political stability is highly of vital importance to secure energy supply, and thus to flourish tourism industry.

The challenge of energy security has consequently geared the tourism sector toward resorting to reliance on decentralized diesel-based technologies to meet the energy needs of hotels in remote areas with an unreliable electricity connection. Yet, dependence on these technologies has not fully solved the problem as other major hindrances came on the scene. One major problem is the scarcity and the staging removal of fuel subsidies. In most MENA countries, fuel prices are notably hiking, despite the drop of international oil prices, because of the continuous cut of subsidies to meet the international standards in the near future. Another stumbling block in reliance on decentralized diesel-based technologies is their substantial operating costs (even at low occupancy rate) which include frequent maintenance, trained technicians and spare parts, just to name a few. Another drawback of utilizing diesel generators is their immense emission of greenhouse gases which in turn poses a serious threat to surrounding environment, and significantly contributes to climate change. This environmental concern would negatively affect hotels and any tourism destination that mainly depend on diesel generators as the world is calling for shifting to renewable energy to alleviate the problem of climate change. Therefore, decentralized diesel-based technologies might not be a feasible option for tourism sector to rely on for the electricity supply.

Solar Energy Technologies: A promising alternative

Solar energy technologies (particularly Photovoltaic, or PV) have recently gained ground as a promising alternative approach to the existing business-as-usual (diesel-based technologies) for power generation. These renewable and sustainable technologies have proved their economic viability, and reliability to supply electricity: statistics suggest investments in PV technologies in the region considerably increased from USD 160 million in 2010 to USD 3.5 billion in 2015[6]— this increment is however expected to continue increasing even more. On the other hand, prices of PV technologies have plummeted by 75% between 2009 and 2014.

In the early phase of solar market in the MENA region, the focus was dedicated to large-scale solar power plant in order to address the energy gap. Nevertheless, with the current technological advancements in solar energy, the focus is now being shifted toward small-scale decentralized generation to provide reliable power supply to remote areas, where there is no utility grid coverage[7]. Furthermore, some studies suggest that complete replacement of polluting diesel generators as a back-up system is highly foreseeable thanks to the great strides made in the battery storage field.

Benefits of using solar energy

The MENA-region's geographic position entails great opportunities for the use of solar energy. With daily direct solar irradiation exceeding 6 kWh/m², the region enjoys enormous potential and favorable conditions for solar energy[8]. With the introduction of feed-in tariff schemes and/or net-metering policies, compensating the transfer of solar energy into the national electricity grid, the region is being transformed to a major hub for solar energy.

Recently, great strides have been made in solar technologies (both PV and CSP) that certainly give them an edge over other generation technologies—particularly diesel generators. PV technology, for instance, offers a distinct set of advantages: its proven lifetime of 25 years, system robustness and flexibility and minimum maintenance. In addition, PV technologies are becoming more and more a cost-competitive generation source, even over its twin CSP technology, due to the steep drops in their cost. This means that levelized cost of energy, a produced by PV is by far less than that produced by diesel generators—albeit the recent declines in oil price. Thanks to the rich steady solar irradiation in the region, PV technologies in particular could also be a cost-efficient energy solution from day one. In fact, solar-based systems could save substantial amounts of energy costs day by day, due to its low maintenance and operating expenses, once the project reaches the break-even point and the initial capital is paid off. Yet, to achieve the highest energy savings, supportive financial instruments and optimized system designs must be properly addressed. Therefore, both forms of solar energy (particularly PV) have been deemed a promising energy source across many sectors and industries in the world.

In tourism sector, solar-based energy technologies (both PV and CSP) bring numerous significant benefits, in addition to the aforementioned ones, that could be summarized as follows:

- Stabilization of energy expenses of hotels, resorts, and other tourist premise regardless of location—even in remote areas.
- Solar energy offers independence from unreliable grid-connections.
- Meeting the sustainability demands of many hotel guests.
- Tourism relies on a clean environment and solar energy serves as a basis for protecting natural heritage
- Taking responsibility and actively engaging toward protecting the environment.
- Costs of conventional energy sources is highly unpredictable, and could hike again in the future.

Energy Profile in MENA

Over the last century, economic development in MENA has primarily leveraged on the region's petroleum and natural gas deposits. In fact, more than a third of the world's petroleum and 20% of the world's natural gas are produced in the MENA region. And roughly 2.5 million barrels of crude oil and 55 billion cubic feet of natural gas are extracted each day[9]. However, only 381 million people inhabit the region, amounting to just 6% of the total global population. Not surprisingly, MENA countries mainly rely on the rich fossil fuel resources for the vast majority of its electricity generation, usually at a heavily subsidized market price.

As illustrated in figure 1, the global energy resources are limited and a mix of alternative electricity sources is needed to secure sufficient power supply in the future. Hence, solar power and thermal are increasing in importance and are envisioned to be the main source of electricity in the future.

Nevertheless, some countries in the region are dependent on imported fossil fuels for their electricity generation and are similarly motivated to find alternatives to the high and fluctuating energy costs. Especially for countries importing fossil fuels, whilst subsidizing electricity, suffer from the large opportunity costs. A switch to solar energy can be a great relief for many nations' government spending.

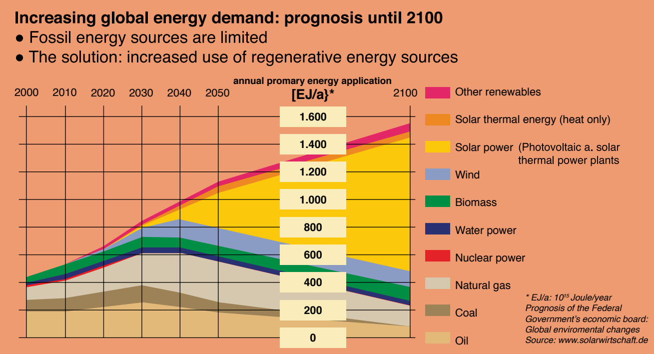

Figure 1: Global energy resource prognosis until 2100.

According to the chairman Vahid Fotuhi of the Emirates Solar Industries Association (ESIA), the population in the MENA-region is continuously growing, with over 50% under the age of 25. With the depletion of hydrocarbon reserves, the region's governments are looking for alternative energy sources. Important is the development of new policies to support the use and ease the shift from conventional electricity toward the generation of solar energy.

Electricity subsidies in MENA

While exact figures vary from year to year, fossil fuel subsidies represent a major bulk of the state's household budget. For instance, in the Kingdom of Saudi Arabia, natural gas is supplied to power plants at a rate of USD0.75/MMBTU and petroleum at USD2.7-4.3 per barrel, representing only a small fraction of the international market prices. Moreover, electricity is subsidized at different points of its production. The fuel inputs are sponsored, whilst the electricity output is repeatedly subsidized for the end-consumer. With lifting electricity subsidies, solar energy increases in its competitiveness and government spending is effectively lowered.

ABOUT THE TECHNICAL MANUAL ON SOLAR SYSTEMS FOR THE HOTEL SECTOR IN THE MENA-REGION

The manual intends to support the national (Egypt) and regional cross-border cooperation and knowhow transfer on employment promotion through RE/EE in the MENA region. RCREEE in cooperation with GIZ are supporting the regional project "RE-ACTIVATE" for "Promoting Employment through Renewable Energy and Energy Efficiency (RE/EE) in the Middle East and North Africa (MENA) (RE-ACTIVATE)", funded by the Federal Ministry for Economic Cooperation and Development (BMZ). The technical manual is being developed under RE-ACTIVATE project and aims to discuss the opportunities for solar Photovoltaic (PV) and solar thermal applications for the hotel sector in the MENA-region as one of the labor and energy intensive sectors, with a special focus on Egypt as a pilot area to serve hoteliers, solar companies and investors in the MENA region.

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[1] Middle East should continue to invest in tourism, World Travel and Tourism Council
[2] Green Hotels & Responsible Tourism Initiative
[3] Griffiths, Steven. "A review and assessment of energy policy in the Middle East and North Africa region." Energy Policy 102 (2017): 249-269.
[4] El-Katiri, L. (2014). A Roadmap for Sustainable Energy for the Middle East and North Africa. The Oxford Institute for Energy Studies.
[5] Asharq Al-Awsat newspaper, August 30th, 2014

[6] Yemen faces threat of economic collapse, Financial Times, 2011 (link)
[7] El-Katiri, L. (2014). A Roadmap for Sustainable Energy for the Middle East and North Africa. The Oxford Institute for Energy Studies.
[8] Diesel to Solar Transformation – Assessing Untapped Solar Potential in Existing Off-grid Systems
[9] Use of Solar Energy in the Middle East, 2011 (link)
[10] How Much Oil in the Middle East? GeoExPRO (link)

01

SOLAR ENERGY IN HOTELS

Chapter One

1.0 BASICS OF SOLAR ENERGY

The sun radiates the earth's atmosphere with a power of 1,370W/m² per year, also known as the solar constant. Due to water vapour and ice crystals, the annual solar radiation reaching the surface of the earth is reduced to approx. 600-1,000W/m². Nevertheless, each year roughly 219 billion GW/h are naturally generated, which represent 2,500 times the world's energy needs. Incoming global irradiation varies between 50W/m² - 1,000W/m², irradiation is split into direct and diffused irradiation. For solar thermal technology, both kinds of irradiation can be absorbed through the collectors, whereas for solar power systems, energy generation is mainly possible at direct irradiation.

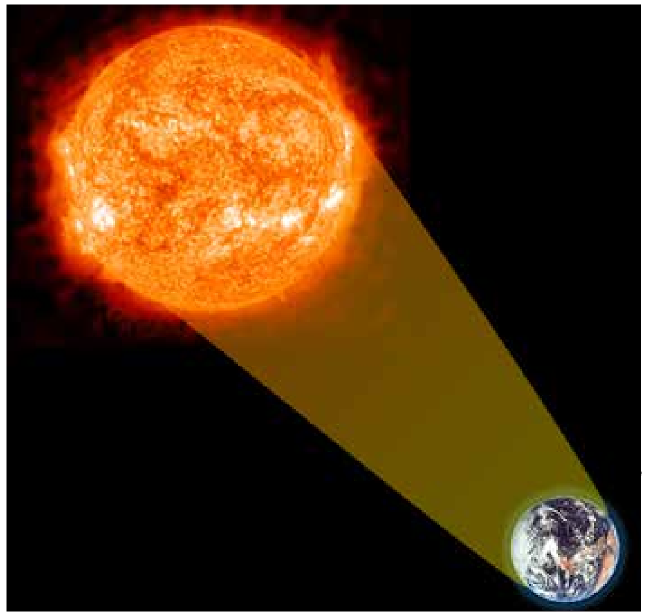


Figure 2: Solar constant of 1370 W/m²

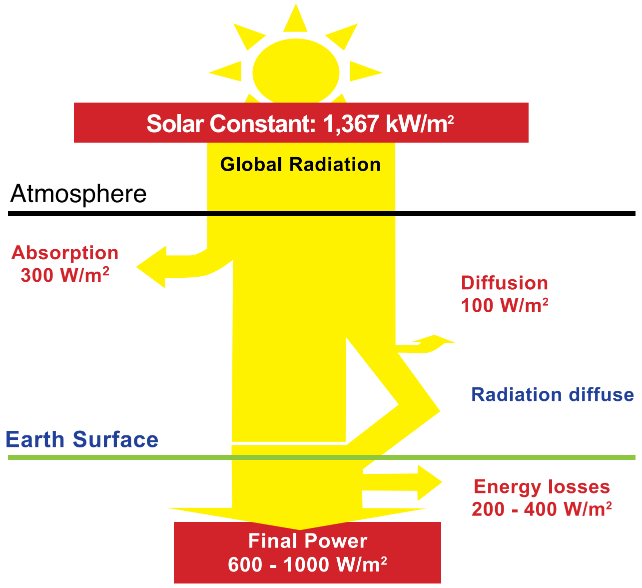


Figure 3: Solar irradiation, absorption and dispersion losses

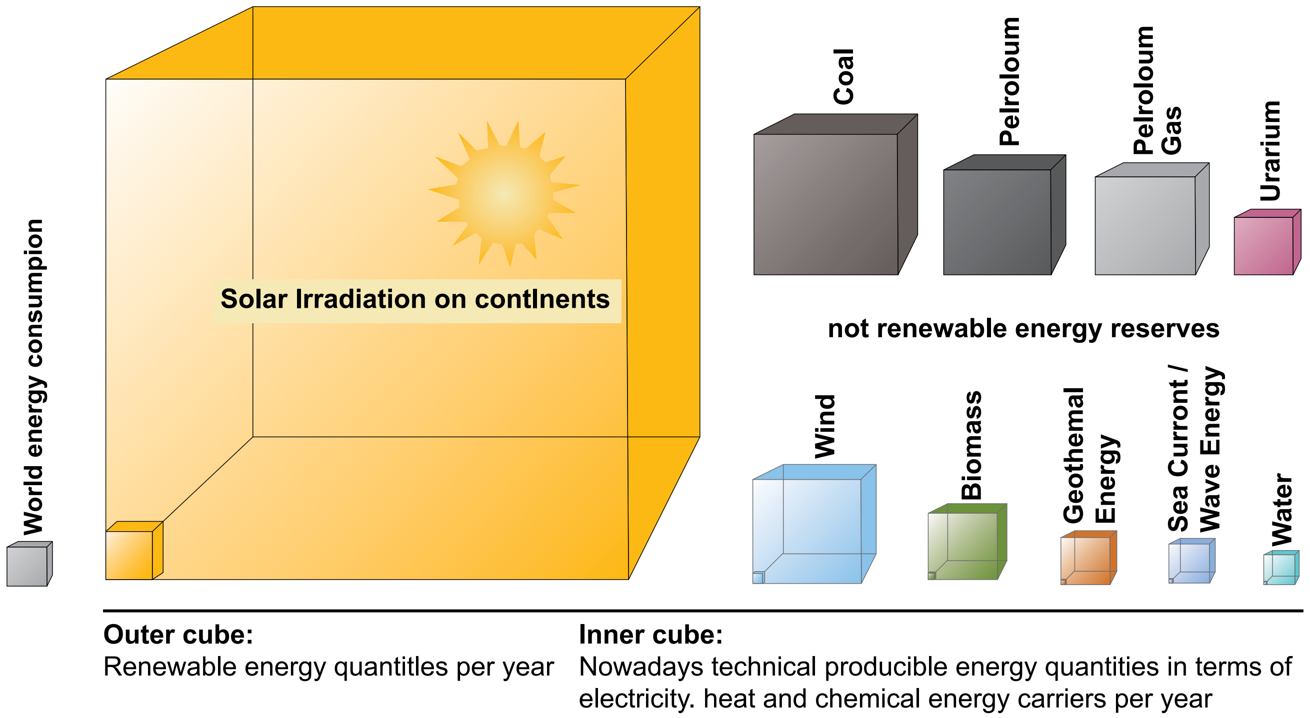
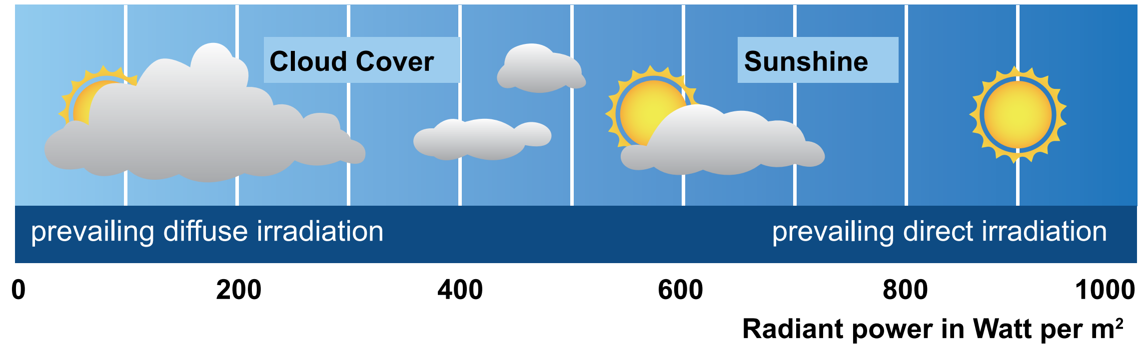


Figure 4: Solar irradiation vs. worldwide energy needs



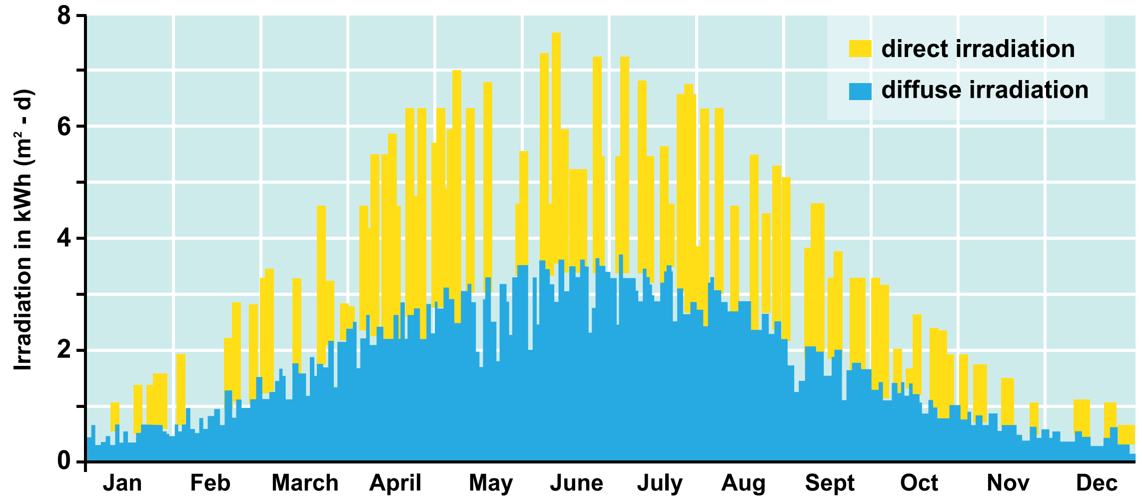


Figure 5: Yearly solar irradiation output in W/m²

In the MENA-region, the average global irradiation reaches 2,600 kW/m² per year and therefore significantly higher compared to just 1,000kW/h in Germany (Figure 8). Thus, the weather conditions in the MENA-region are a great potential for solar thermal and power systems. For instance, on a sunny day 1m² of solar collectors can heat up to 70-80 liters of domestic hot water or can save approx. 165-280l oil. Figure 6 and 7 display the daily and yearly solar irradiation in Cairo, Egypt, respectively. The figures show that the maximum sunshine irradiance is in June and July, at times in which Egypt and other countries in the region use energy intensive cooling systems (e.g. air-conditioning) in most of their facilities. Thus, the enormous solar potential in Egypt and the region can lead to significant cost savings.

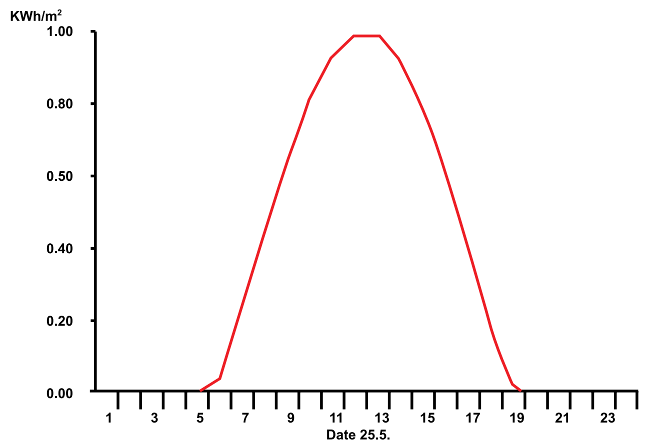


Figure 6: Daily solar energy output in kWh/m² (horizontal) in Cairo

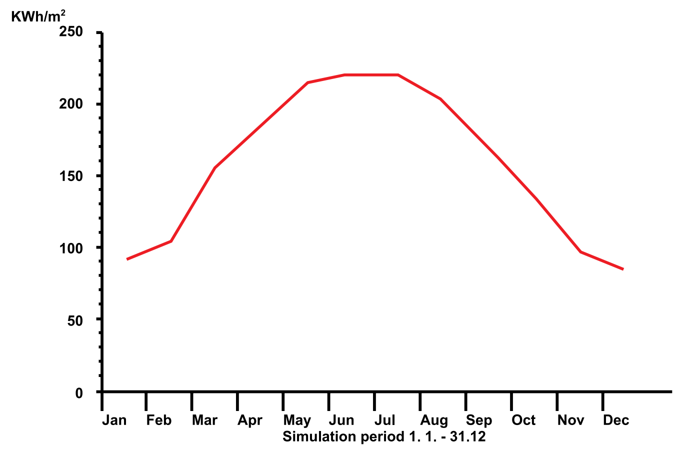


Figure 7: Yearly solar energy output in kWh/m² (horizontal) in Cairo

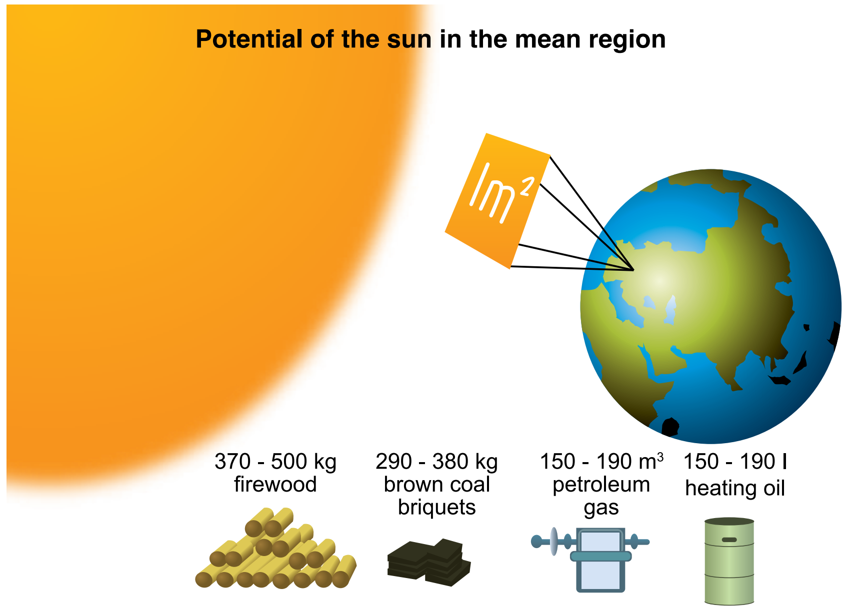


Figure 8: Potential of solar energy in MENA-region 1 m²

The solar radiation map presents the average amount of solar energy irradiation expected in each country within the MENA-region (Figures 9 and 10).

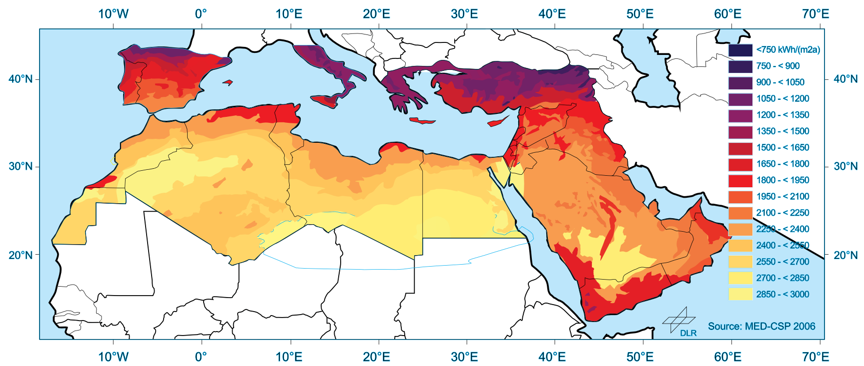


Figure 9: Annual sum of direct irradiation in kWh/m² in MENA-region

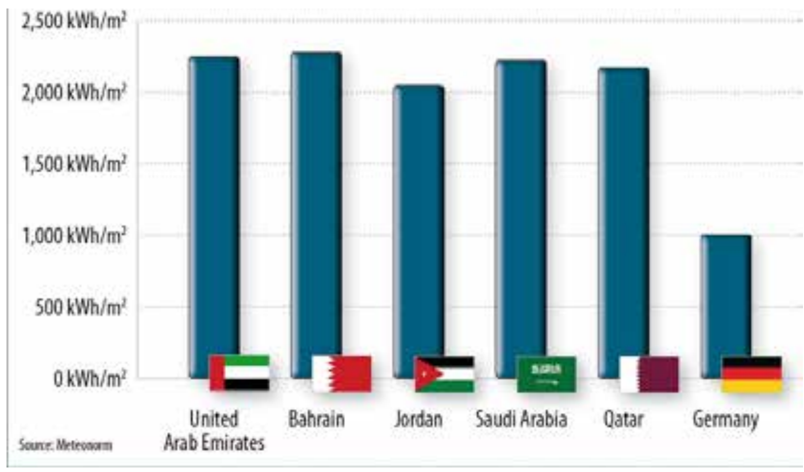


Figure 10: Solar irradiation level MENA-region vs. Germany

1.1 HOW DOES A SOLAR SYSTEM WORK?

BASIC PRINCIPLES OF SOLAR POWER AND HEAT

Solar power and solar thermal systems transform sun radiation into clean energy. Although both systems generate energy during sunshine hours only, the working principles of these technologies are quite different (see figure 11).

Solar cells (aka Photovoltaic cells) transform sunlight directly into electricity. Photovoltaic (PV) is derived from the process of converting light (photons) to electricity (current), known as the PV effect. Solar power systems generate electrical power that is equal to the power provided by a public grid or a generator. Conventional large-scale solar systems used for hotels generate AC power with a single phase voltage of 220V or three-phase 380V. The solar power is used for any electrical application equal to the electricity sourced from a public grid. In case the solar system is not an independent system serving one power outlet only (e.g. a pump station), the generated solar power can be distributed via the hotel's internal grid to any energy consumer connected to the grid.
In solar thermal systems, power is used to generate heat in form of hot water. Solar thermal applications other than solar power systems are only used when hot water or heat is needed. For instance, solar thermal applications are useful to generate hot water for lavatories, kitchen and laundry appliances, pool, or spa facilities.

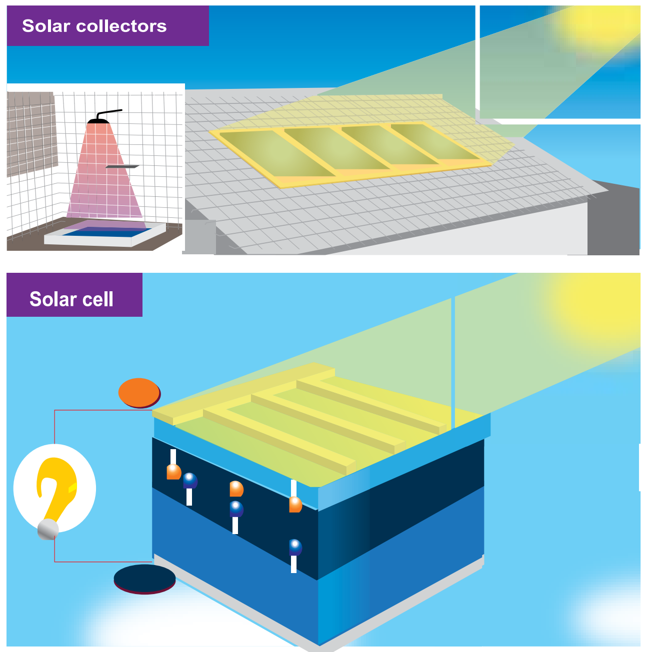


Figure 11: Principles of solar power and solar thermal systems

Figure 12: Solar power and solar thermal systems

The design of the solar power and thermal systems depicts the maximum possible energy generation during sunshine hours, according to the average sun irradiation per year. Due to the nature of solar energy, the amount of energy generated can deviate from the average performance of the systems, depending on the daily weather condition. To stabilize the performance, the systems can be enhanced with a back-up energy source from a public grid, a diesel generator for solar power or a boiler for solar thermal systems.

Since solar energy is limited to the daily sunshine hours, a back-up system is needed if electricity is required during evening and night time or to overcome periods of bad weather conditions (e.g. cloudy days). Therefore, the back-up system has to provide an integrated energy storage with the capacity of the energy demand during non-sunshine hours. For a solar thermal system, the storage is usually a hot water tank, sized according to the demand profile during non-sunshine hours. For a solar power system, appropriately sized batteries, including a charge control and a management system to switch between solar energy and batteries are required.

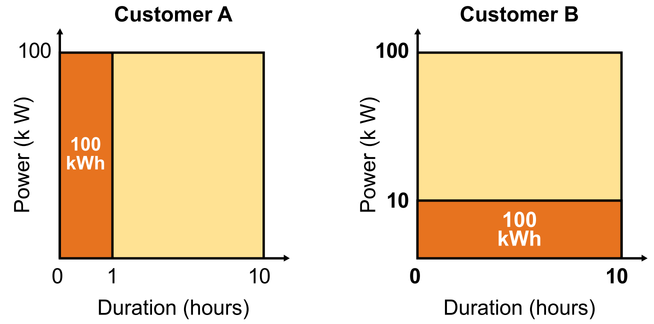
System	Solar Power	Solar Thermal
		
Energy	Electricity	Heat/Hot water
Application	Power supply for any application	Heat or hot water applications (e.g. laundry, shower, kitchen appliances, heating systems, pool heating, wellness and spa facilities)
Generating technologies	Photovoltaic module (solar/PV cells)	Solar collector (solar absorber)
Types of generators	Polycrystalline modules; Monocrystalline modules; Thin-film modules	Flat plate collector; Evacuated tube collector; Swimming pool absorber
Working principle	Solar cells absorb sun radiation and release electrons that generate electricity, if connected to an electric circle.	Sun radiation heats up the water running through the solar collectors, which generate heat.
How to identify	Thin panels with a shiny surface in either blue, brown or color.	A glazed box with black or blue flat plate collectors or glass tubes connected to a manifold.
Efficiency	The solar panels have an efficiency rate between 15-20% depending on the module type and installation conditions (e.g. location, inclination, orientation).	The solar thermal collectors have an efficiency rate of up to 50%, depending on the temperature of the hot water, the quality of the components as well as the installation and location of the system.
Interface to Hotel	Inverters	Not applicable
Connection point	The solar power system is connected to either the mains or sub-distribution board of the hotel.	The solar thermal system is connected to the hot water system of the hotel.
Storage	Batteries	Hot water storage tank
Back-up / supplementary energy	Public grid or generator	Boiler or electric heaters
Connection	Wiring	Piping with insulation

EXCURSION 1

POWER AND ENERGY

The unit of power is indicated as W, kW or MW and describes the capacity that is needed by a consumer. To depict the energy consumption of a consumer, the time factor has to be known. Therefore, the unit of energy is indicated as Wh, kWh, MWh or as kJ, MJ (1J = 1 Ws), describing how much energy is needed over time. The unit of energy is equal to the consumption of fuel or electricity. For each type of fuel, the consumption can be calculated based on the specific energy content of the fuel, e.g. 1 liter of diesel contains an energy of approx. 10 kWh (10 kWh/l), which is equal to a power of 1 kW for 10 h

E = P . t
Where E = Energy, P = Power, t = time



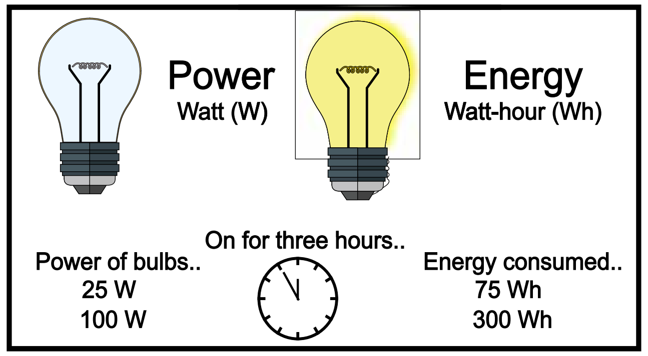


Figure 13: Power and energy conversion

EXAMPLE 1

Air-conditioning: 200 kW

Operating time with constant demand: 12 hours

Energy consumption: 200 kW × 12 h = 2,400 kWh
To transfer from J to kWh the following factor is used:

1 kWh = 3.6 MJ

1 MJ = 0.278 kWh

Another unit for energy is 1,000 kcal =1.163 kWh =4.1868 MJ

Each fuel used to generate heat or power via a boiler or generator has its specific energy content (i.e. 10 kWh/l).

For thermal systems using water as a medium, the actual power generated can be calculated by the flow rate of the water through the collectors and the inlet-/outlet temperatures, as explained in the following example.

$P = m \,.\, cp \,.\, (T_{out} – T_{in})$ in kW

m· = mass flow of water in kg/s

T_{out} = outlet temperature in °C

T_{in} = inlet temperature in °C

cp = thermal capacity of water: 4.18 kWs/kg K

EXAMPLE 1 (SIMPLIFIED)

Measured flow rate: 5.0 m^3/h = 5,000 l/h = 1.38 l/s

Density of water:rho = 1.0 kg/l

Mass flow: 1.38 kg/s

T_{out}: 70°C

T_{in}: 30°C

P = 1.38 kg/s . 4.18 kWs/kgK . (70 – 30) K

P = 230.74 kW

Energy can be calculated using the mass and the inlet-/outlet temperature, as follows:

m × cp × (T^{out} – T^{in}) x 1 h/3,600 s in kWh

m = mass of water in kg

T_{out} = outlet temperature in °C

T_{in} = inlet temperature in °C

cp = thermal capacity of water: 41.8 kWs/kg K

EXAMPLE 2

Hot volume water per day: 20.0 m^3 = 20,000 l

Density of water: rho = 1.0 kg/l

Mass of water: 20,000 kg

T_{hot} water: 55°C

T_{cold} water: 20°C

Q = 20,000 kg . 4.18k Ws/kgK . (55 – 20) K × 1h/3,600s

P = 813 kWh

1.2 BASICS OF A SOLAR POWER SYSTEM

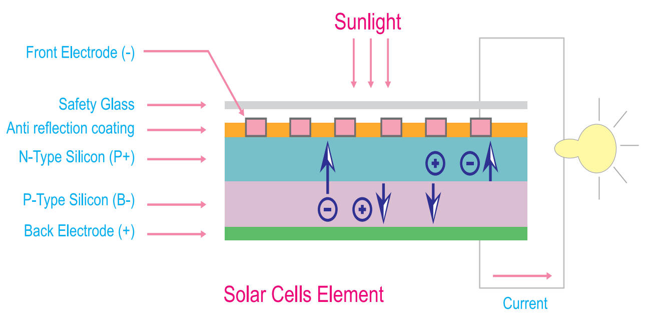


Figure 14: Principle of PV

FIgure 15: PV modules

Solar power was first recognized in 1954 when scientists at Bell Telephone discovered that silicon created an electric charge when exposed to sunlight. Soon after, solar cells were being used to power space satellites and smaller items such as calculators and watches. The PV modules, also called PV panels, are the driving engines of a solar energy power system. Solar irradiation is transformed in the modules into electric energy via the core component of the PV panel, the solar cell. Today, millions of people power their homes, hotels and businesses with individual solar PV systems. Even public utilities are already relying on PV technology for large power stations. The solar cells are combined in frames and glazed into a solar module or panel. Several panels are connected to form solar arrays according to the design and size of the solar power system (Figure 15).

As solar panels in fact generate DC (direct current), the solar systems are equipped with inverters to converted the DC power into AC (alternating current) power. Any larger electrical device needs AC power in order to be operated. Only very small off-grid applications use DC power to charge batteries or to operate smaller devices directly.

EXCURSION 2

A Solar Thermal System

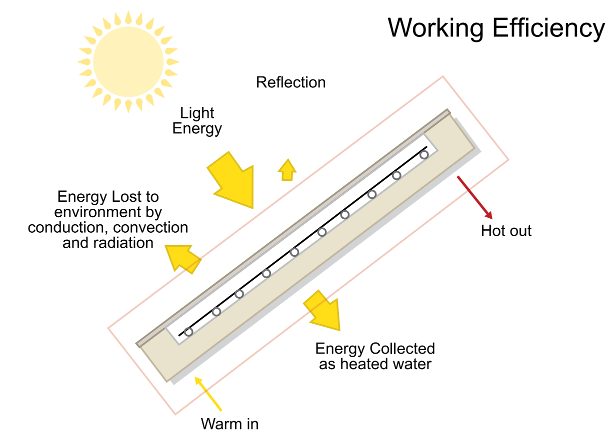


Figure 16: Working efficiency of a solar thermal system

EFFICIENCY

The efficiency of a solar power system describes how much solar energy is generated during sunshine hours that can be converted into electricity.

η = Electricity/Solar irradiation

The efficiency is calculated based on actual power values:

ηποωερ = Output power W / solar irradiation W

η energy = Electricity generated during sunshine hours in kWh / Solar irradiation of the day in kWh

It is important to separate between the efficiency of a solar cell of a PV module and the efficiency of the entire solar system. Each system causes some efficiency losses created by inverters, piping and wiring when transferring the generated solar energy to its end consumer (i.e. light bulb).

EXCURSION 3

BASED ON POWER:

Solar Irradiation: 800 W/m²

Installed collector area: 200 m²

Irradiation on Collectors:

200 m² × 800 W/m² = 160 kW

Output of the system: 96 kW (measured flow rate and in let/outlet temperatures of collector area)

EFFICIENCY:

ηποωερ = 96 kW/160 kW = 60%

BASED ON ENERGY:

Solar irradiation of the day:

Figure 17: Inverters in a solar power system

5 kWh/m² (measured by irradiation sensors)

Installed collector area: 200 m²

Total solar energy: 1,000 kWh

OUTPUT OF THE SYSTEM:

450 kWh (measured by heat meter)

EFFICIENCY:

η_{energy} = 450 kWh/1,000 kWh = 45%

In practice solar power systems have an efficiency of 15-20 %. For a location with a global irradiation of 1,800 kWh/m2 per year, a solar power system generates approx. 300 kWh/m² annually. For conventional PV modules with a size of 1.6m2 and a capacity of 260 Wp, 1 kWp (kilo Watt peak) installed can generate around 1,850 kWh per year.

EXCURSION 4

kWp

The unit kWp (kilo Watt peak) is used to describe the size of a solar power system. It depicts the performance of the installed modules under the so-called Standard Test Conditions (STC). The STC tests and certifies the solar panels under an irradiation of 1,000 W/m², Air mass of 1.5 and a temperature of 25°C. However, irradiation and temperatures vary by country and the performance of the system is further influenced by the inclination and orientation of the PV panels. Therefore, the real output of a solar system in operation is always different from the STC values. Yet, the STC values facilitate the comparison between systems and are useful when simulating the solar output under the project's conditions.

EXAMPLE 4 (SIMPLIFIED)

A system of 100 kWp is installed in a location with an expected operation temperature of the PV modules at 70°C or more (deserted area).

Standard Test Condition: 25°C

Temperature coefficient for power: -0.4%/degree (datasheet of photovoltaic modules)

Operation temperature: 70°C

Temperature difference to STC conditions: 45K

Output reduced by: -0.4%/K . 45K = 18%

Max power under operational conditions: 82 kW

The space requirement for a solar power system depends on the type of installation and the inclination of the solar panels. For roof parallel installations, where shading effects can be disregarded, approx. 5-6 m² are necessary to install 1 kWp. For on-ground or flat roof installations, additional space between the solar panels is necessary. The shading effect can reduce the solar output of the system, as not all solar panels are exposed to direct sun irradiation. To prevent the shading effect, 1 kWp of solar panels requires an area of 10-15 m².

SOLAR POWER SYSTEMS CAN BE CATEGORISED INTO THREE TYPES:

1- SMALL INDEPENDENT UNITS

The small independent solar power units only operate on solar energy and are not connected to a public grid. They are usually used for streetlights, garden lighting, small watering pumps or any other limited energy consuming device.

2-SUPPORT SYSTEMS

For the support systems, solar energy is not the only source of energy, but is rather used as part of the energy mix to cover the electricity demand. In such a system, the hotel relies mainly on their main power source e.g. the public grid and the solar system covers only partial demand during daytime.

3-STAND-ALONE SYSTEMS

In the stand-alone system, solar energy is the main source of electricity. An additional back-up system needs to be integrated to cover the energy demand during night time. The system can be enhanced with either another source of renewable energy such as wind turbines or a conventional source, such as diesel generators or batteries.

The key factor for the installation and integration of a solar system is the available space and type of support structure used. The energy transfer from the solar system to the internal grid or any other energy consumer is quite simple and flexible, since the connection and installation rest on wiring. Although through wiring a small fraction of the system's efficiency is lost, these losses can be reduced to a minimum with an accurate design and sizing of the components.

It is crucial to understand, that solar power systems are usually not designed to supply a single energy consumer directly. Special solutions such as pump stations away from grid connections are precisely designed to serve one consumer only. However, conventional solar systems are connected to the internal grid, which distributes the needed electricity according to the demand of the energy consumers connected to the internal grid. In fact, it is more efficient and economic to transfer all generated solar power to a single grid on the main distribution line. In case the systems delivers insufficient solar energy, back-up systems can cover the missing gap, whereas in times of excess, solar energy can be either reduced, stored or fed into the national grid, if feed-in tariff or net-metering schemes are in place.

THE EFFICIENCY OF A SOLAR POWER SYSTEM DEPENDS ON THE FOLLOWING FACTORS:

- Choice of efficient module technology and type of modules
- Design of module strings and areas
- Choice of inverters, suitable to the modules and design
- Losses in wiring
- Operational conditions (e.g. temperatures)
- Project installation (e.g. orientation, inclination, shading)
- Location
- Power demand profile in case of oversized systems

MAIN COMPONENTS OF A SOLAR POWER SYSTEM PHOTOVOLTAIC MODULES

The PV modules/PV panels are the main component of a solar power system. In the modules, solar radiation is converted into electric energy. When several modules are connected in series to strings, the modules generate 600-1000V DC (direct current).

Figure 18: Installed PV modules

The most common module is the crystalline technology based on silicon, in which several solar cells are framed in one module/panel. There are two different crystalline types available in the market: monocrystalline and polycrystalline.

Monocrystalline modules can be identified by their homogeneous dark shining blue or black surface. As they are produced of pure silicon, the cells consist of a single crystal only. The efficiency of monocrystalline modules is higher compared to other module technologies. They are also higher priced, because of the stringent requirements for the purity of its material.

Polycrystalline cells are also made of silicon. However, during the process, the silicon grows in several crystals, which is visible on the borders of the solar cells. The efficiency of the polycrystalline modules is a few per cent lower than monocrystalline modules, yet when considering the price-performance ratio, it is often the preferred module choice. Only in locations where space for the installation is limited, monocrystalline might be the most economic solution.

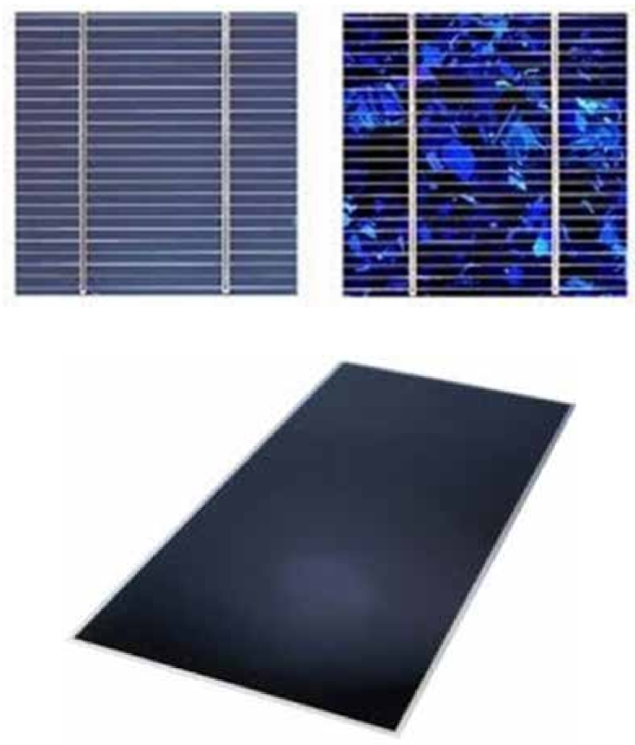


Figure 19: PV Panels – Monocrystalline, Polycrystalline and Thin Film modules

Another technology available in market is the so-called thin-film technology, where semi-conductor materials are coated onto a carrying material, such as glass. In the future, thin-film modules seem to be the most promising technology, as far less material is used compared to silicon modules. On the downside, their efficiency is approx. 50% lower than the crystalline modules. Therefore, the needed space to realize the same power size is higher, which increases the costs for wiring and support structures.

Another reason why thin-film modules with their current specification are not the most cost-efficient modules is the mass-production of crystalline modules in low cost countries. Thin-film panels are nowadays mostly used in projects with high aesthetic requirements, as the surface colour of the modules can be changed, or where the orientation of the solar modules is not optimal. In case of sub-optimal orientation, the thin-film technology has an advantage over the poly- and monocrystalline modules, as it can use a wider solar irradiation range, which is suitable for areas with higher diffused irradiation (e.g. fine dust in the air). Another advantage of thin-film modules is the higher temperature resistance, making it the preferred module for projects in deserts or other hot climate zones. On the downside, some thin-film modules are still made out of heavy metals such as Cadmium or Arsenic, which are difficult to recycle once the panels are disposed.

The lifetime of the poly- and monocrystalline panels is up to 25 years. For thin-film, especially the new thin-film technology, it is best to check with the individual suppliers regarding warranty, since long-term data is not yet available.

An aging effect, also called degradation, is normal for all types of modules, with a loss in performance of 0.5-1% per year, depending on technology and supplier.

The system provider chooses the suitable modules for the location, purpose and budget of the system design and combines the panels with the appropriate inverters to ensure a well functioning and safely operating system for a wide range of possible conditions at the project's site.

On the backside of the panels, PV modules are equipped with module connection boxes, which are the interface to the complete solar system (Figure 20). These boxes include important bypass diodes, which ensure the operation of each solar cell. The module wire connects the modules to the string box or to the inverter directly. The wires need to be long enough to avoid any tension in the installation and have to be equipped with a certified, waterproof PV connector to guarantee long-lasting operations.

Figure 20: Module connection box at the backside of PV modules

Each module has its own characteristics, regarding voltage U (volt) and current I (ampere) under different operating conditions (e.g. irradiation and temperature). These characteristics are listed on the data sheets of the PV module as diagrams and/or coefficients in %/K, mV/K or mA/K. The power P (Watt) is the product of current and voltage. The power curve is plotted depending on the voltage. It reaches its maximum at the maximum power point (MPP), which resembles the highest power the PV module is generating in a certain time span. Thus, the MPP tracking system is a key function of any solar inverter.

Each solar panel has similar characteristics, regardless of its brand or technology. For all solar panel types, the higher the irradiation, the higher the output current of the panel. When designing a solar system, local irradiation conditions have to be taken into account with respect to the minimum and average irradiation per year to ensure safe and stable operations at optimal efficiency.

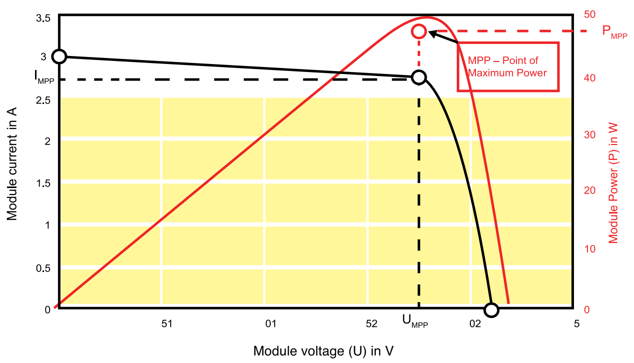


Figure 21: I-U diagram with MPP of a PV panel

It is crucial to understand that the effectiveness of any type of solar panel is lowered at increasing temperatures as displayed in figure 22.The voltage in the solar system and the correct string design has to be adjusted according to the input range of the inverters used. Particularly desert applications need to be designed by experienced system providers to guarantee an optimally operating solar system, as only suitable module types and inverters can withstand the extreme weather conditions in hot climate zones.

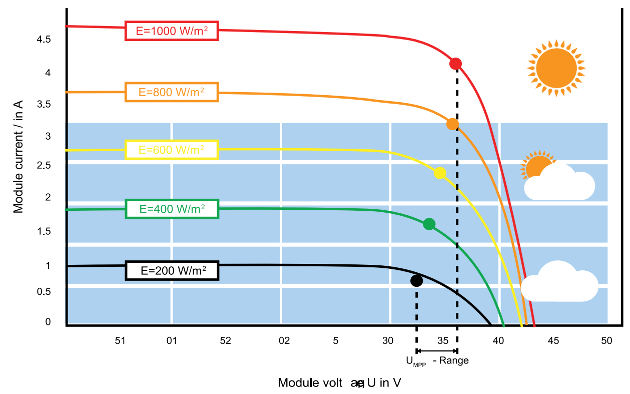


Figure 22: Output of a PV module depending on irradiation

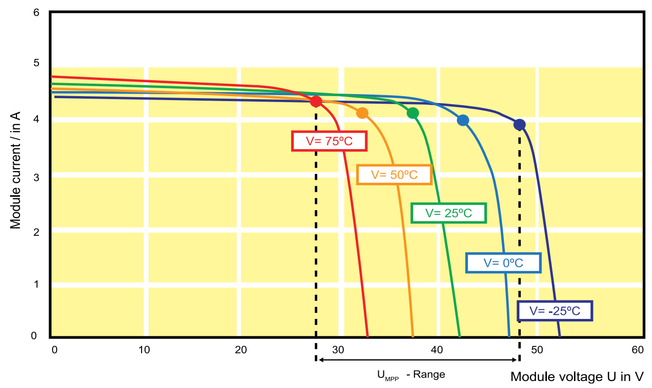


Figure 23: Output of a PV module depending on module temperature

The characteristics of the solar panels and the temperature coefficient are listed on the product sheet of the solar modules. These are standard values in %/K, mV/K or mA/K and indicate the decrease of power per degree higher than the STC of 25°C. The design and simulation of the system must include these factors.

CS6P-235/240/245/250/255P

Electrical Data

STC	CS6P-235P	CS6P-240P	CS6P-245P	CS6P-250P	CS6P-255P
Nominal Maximum Power (Pmax)	235W	240W	245W	250W	255W
Optimum Operating Voltage (Vmp)	29.8V	29.9V	30.0V	30.1V	30.2V
Optimum Operating Current (Imp)	7.90A	8.03A	8.17A	8.30A	8.43A
Open Circuit Voltage (Voc)	36.9V	37.0V	37.1V	37.2V	37.4V
Short Circuit Current (Isc)	8.46A	8.59A	8.74A	8.87A	9.00A
Module Efficiency	14.61%	14.92%	15.23%	15.54%	15.85%
Operating Temperature	-40℃~+85℃				
Maximum System Voltage	1000V (IEC) /600V (UL)				
Maximum Series Fuse Rating	15A				
Application Classification	Class A				
Power Tolerance	0 ~ +5W				

Under Standard Test Conditions (STC) of irradiance of 1000W/m², spectrum AM 1.5 and cell temperature of 25℃

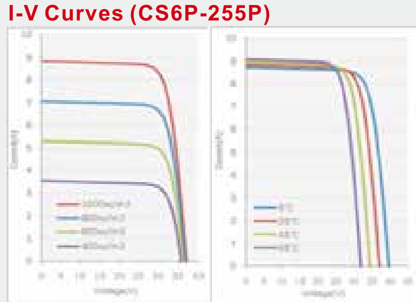
NOCT	CS6P-235P	CS6P-240P	CS6P-245P	CS6P-250P	CS6P-255P
Nominal Maximum Power (Pmax)	170W	174W	178W	181W	185W
Optimum Operating Voltage (Vmp)	27.2V	27.3V	27.4V	27.5V	27.5V
Optimum Operating Current (Imp)	6.27A	6.38A	6.49A	6.60A	6.71A
Open Circuit Voltage (Voc)	33.9V	34.0V	34.1V	34.2V	34.4V
Short Circuit Current (Isc)	6.86A	6.96A	7.08A	7.19A	7.29A

Under Normal Operating Cell Temperature, Irradiance of 800 W/m², spectrum AM 1.5, ambient temperature 20℃, wind speed 1 m/s

Mechanical Data

Cell Type	Poly-crystalline 156 x 156mm, 3 or 4 Busbars
Cell Arrangement	60 (6 x 10)
Dimensions	1638 x 982 x 40mm (64.5 x 38.7 x 1.57in)
Weight	19kg (41.9 lbs)
Front Cover	3.2mm Tempered glass
Frame Material	Anodized aluminium alloy
J-BOX	IP65 or IP67, 3 diodes
Cable	4mm²(IEC)/12AWG(UL), 1000mm
Connectors	MC4 or MC4 Comparable
Standard Packaging (Modules per Pallet)	24pcs
Module Pieces per container (40 ft . Container)	672pcs (40'HQ)

I-V Curves (CS6P-255P)



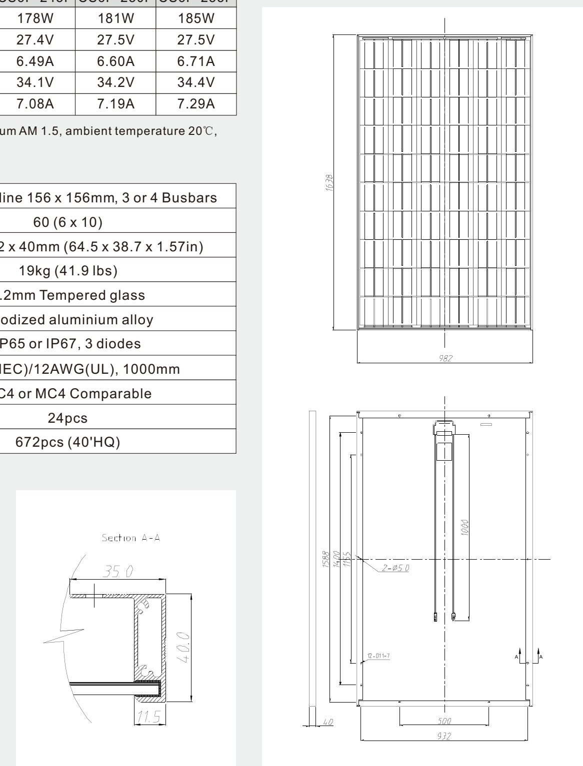
Temperature Characteristics

Temperature Coefficient	Pmax	-0.43%/℃
	Voc	-0.34 %/℃
	Isc	0.065 %/℃
Normal Operating Cell Temperature		45±2℃

Performance at Low Irradiance

Industry leading performance at low irradiation environment, +95.5% module efficiency from an irradiance of 1000w/m² to 200w/m² (AM 1.5, 25 ℃)

Engineering Drawings



*Specifications included in this datasheet are subject to change without prior notice.

About Canadian Solar

Canadian Solar Inc. is one of the world's largest solar companies. As a leading vertically-integrated manufacturer of ingots, wafers, cells, solar modules and solar systems, Canadian Solar delivers solar power products of uncompromising quality to worldwide customers. Canadian Solar's world class team of professionals works closely with our customers to provide them with solutions for all their solar needs.

Canadian Solar was founded in Canada in 2001 and was successfully listed on NASDAQ Exchange (symbol: CSIQ) in November 2006. Canadian Solar has cell manufacturing capacity of 1.5GW and module manufacturing capacity of 2.3GW.

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Figure 24: Typical data sheet of PV modules

The module temperature is an essential factor when sizing the solar systems. The temperature of the module is significantly higher than the ambient temperature. For instance at desert lodges, the module can reach a temperature of above 80°C, which reduces the output power of the modules substantially. It is therefore important to be aware of the weather conditions at the location of the system and its effect on the panel performance.

ESSENTIALS OF PV MODULES:

- Good price-performance ratio
- Temperature coefficients for design as low as possible
- Range of allowed operating temperatures must fit to conditions
- Modules suitable for sea climate conditions (if hotel is along the coast)
- Connection boxes an lamination stable under high operating temperatures
- Suitable packaging to ensure safe transportation to the hotel/project site

REQUIRED STANDARDS FOR PV MODULES:

- IEC 61215 PV modules with crystalline cells (or equal UL 1703),
- IEC 61646 thin-film PV modules
- IEC 61730 safety qualification of PV modules
- Module connection box minimum IP 55 or IP 65 (category 1 acc. to EN 60259)
- Protection class II
- EN 50548 connection boxes for PV modules

SOLAR INVERTERS

The inverter is the key component of the solar power system, as it converts the DC (direct current) into AC (alternating current) power suitable for any electronic device. The inverter either synchronizes with an existing grid or builds its own grid. According to the system size and design, either single- or three-phase inverters are needed.

Figure 25: Solar inverter installations

AN INVERTER HAS TO CARRY OUT THE FOLLOWING FUNCTIONS:

- Convert DC into AC power
- Adjust the operation according to the MPP[1] of the power modules
- Synchronize the generated solar power with a public grid; internal generator grid; create an own stable grid in case of an island solar energy solution
- Collect operating data and visualize the status of operation
- Include protection devices for DC and AC side

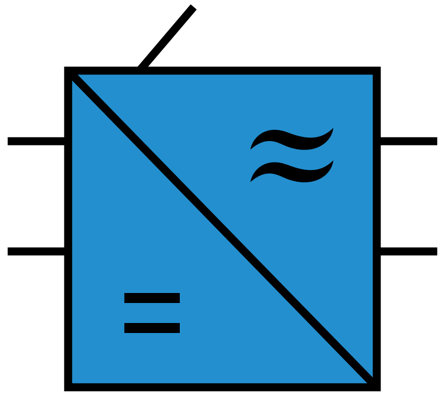

Figure 26: Symbol for a solar inverter

For grid-connected systems, standard solar inverters can be used, when another power source (i.e. public grid or Diesel generator) creates the dominating power. Thereafter, the inverter synchronizes the solar power with the voltage and frequency of the grid.

For solar power systems, with a direct connection from the consumer to the inverter, only special inverters are applicable. These are developed precisely for an independent single consumer, such as water pump station or other three-phase motors with similar characteristics.

These inverters must include a MPP tracking on the solar side and a frequency inverter or variable speed drive on the consumer side, in order to adjust the solar power to the electricity demand.

Figure 27: Solar Pump Inverter for direct connection to a motor

Figure 28: Standard inverters for grid connection

1: Maximum Power Point

In island solutions, solar power is the main or only power source and requires special island inverters. Contrarily to conventional inverters, island inverters do not require a grid connection. The island is created to establish its own stable grid with the needed frequency and voltage according to the electricity demand. When other power sources are used in addition, they must be connected to a separate control system that adjusts itself to the established grid of the island solution.

Figure 29: Island inverter for grid connection
(Source: SMA Solar Technology)

Another special type of inverter is the micro inverter. The micro inverter is a smaller type that converts DC into AC from a single PV module only. To reach the envisioned energy level, several such micro inverters are connected to the internal grid. The advantage is that even very small power units can be individually connected to the solar system, which is an interesting technology for hotels with a bungalow layout. It is the most cost-efficient solution to connect separate small PV panels to the internal grid. A conventional inverter has a much larger capacity and would therefore be too costly to be installed on each bungalow individually.

Figure 30: Solar micro inverter for single PV modules

ESSENTIAL FOR SOLAR INVERTERS:

- For systems with grid connection only certified standard inverters are applicable.
- High efficiency under high ambient temperatures.
- For systems with direct connection to a single consumer only special solar inverters with integrated frequency control and direct solar drive should be used.
- Standard inverters always need another dominating power source to synchronize.
- Island inverters must provide a stable grid over a long period of time.
- Integrated MPP tracking is recommended.
- Inverter MPP range has to match the MPP of the PV modules and string design.
- Variable speed drive and soft start function are recommended for direct connected inverters.

REQUIRED STANDARDS FOR SOLAR INVERTERS:

- IEC 62103 Electronic equipment for use in power installations.
- IEC 62109 Safety of power converters for use in PV power systems.
- Part 2: Particular requirements for inverters.

BATTERIES AND CHARGE CONTROL

Batteries are used in grid-connected solar systems to increase the efficiency and rate of self-consumption of the system. At peak sunshine hours, excess solar energy is stored in the batteries and is available at times with insufficient solar irradiation during the day. The batteries increase the operating time of the solar system and store excess generated solar energy during sunshine hours, which would otherwise be lost. The batteries do not offer a full capacity back-up system for night time demand, but rather an economic solution to store excess solar energy at peak times, whilst stabilizing the solar power at times with sunshine interruptions (e.g. clouds). Adding batteries to the solar design does not influence the sizing of the PV system.

Another option is to design the solar system with additional batteries based on the gap between the total energy demand profile and maximum possible generated solar energy during sunshine hours. In this case, the batteries have to be designed based on the expected demand after sunset and the PV system has to be oversized to generate sufficient energy to satisfy the energy demand while loading the batteries during sunshine hours.

In stand-alone solar power systems, batteries as a back-up power source are the key parts to maintain power supplyduring non-sunshine hours and night time. The solar and back-up system have to be designed according to accurate figures with respect to the energy demand profile, weather conditions and aging and maintenance, in order to ensure the system's lifelong operation of 25 years.

The lifetime of batteries is based on the number of discharge and charge cycles. In solar systems with batteries as back-up energy storage, deep-cycle batteries are a must, as they are regularly discharged of most of their capacity reaching up to 80% before being recharged again. When deciding the suitable battery bank, the nominal battery capacity is not a crucial factor, but the degree of discharge (DoD) in operation. The DoD is based on the battery technology, the assumed operating conditions and the expected lifetime of the batteries. As a general rule, the higher the DoD, the shorter the lifetime of the battery.

When designing a solar system including batteries for desert applications, the harsh weather conditions have to be considered, as they negatively affect the lifetime and efficiency of the batteries used.

EXAMPLE 4

Required power demand:	75 kW
Required operation based on batteries:	10 h
Battery efficiency:	90%
Required energy:	75 kW . 10 h / 0.9 = 833 kWh
DoD designed	50%
Required nominal capacity of battery bank:	1,670 kWh

BATTERY TECHNOLOGIES:

Lead-acid (LA) is one of the most cost-effective batteries. It is a mature technology well suitable for solar power systems. There are two main lead-acid battery types: (1) flooded and (2) sealed batteries. Flooded batteries are the least expensive, but require regular check-ups to ensure electrolyte levels are maintained. They must be properly vented as through charging explosive gases are produced. The sealed batteries (i.e. Absorbed Glass Mat (AGM), Gel Electrolyte (GEL)) are more expensive, but do not require watering or special venting.

Figure 31: Lead Acid Battery (flooded type)

- Best choice for low cost systems

Nickel-Metalhydrate (Ni-MH) batteries have a longer lifetime in systems with daily charge and discharge cycles. Their energy density is not as high as Li-Ion batteries, but their capacity outperforms the standard lead-acid batteries. It is a mature technology and available in a wide product variety. Ni-MH batteries do not contain flammable electrolytes.

Figure 32: Nickel-Metalhydrate battery

Nickel-cadmium (Ni-Cad) batteries are more expensive than lead-acid batteries and their disposal is costly due to the toxic cadmium in the batteries. They require some caution during discharge, because of the chemical 'memory effect'. The Ni-Cad batteries are mainly used for very cold climates and therefore not as suitable for deserted PV systems.

Figure 33: Nickel-cadmium battery

Lithium-ion (Li-ion) batteries are the preferred batteries for off-grid small solar applications and in larger industrial systems. They are more expensive compared to NiCad batteries, but have a higher energy density and lower rates of self-discharge. Li-ion batteries have the same capacity of lead-acid types, but at 20% of the weight. They are sensitive to overheating and flammable in case of extremely hot weather conditions ('thermal runaway').

Figure 34: Lithium-ion battery

Nickel Iron (Ni-Fe) batteries have alkaline electric cells designed based on the original "Edison Cell". The Ni-Fe batteries have a longer lifetime compared to most other batteries, but also suffer high losses during charging and discharging, which adds to the size of the solar system.

Figure 35: Nickel Iron battery

FACTORS INFLUENCING BATTERY LIFETIME:

Causes of premature failure of a battery are:

- Drawing more current than the battery was designed for
- Over-discharging on a regular basis
- Over-charging due to inappropriate voltage setting
- Allowing electrolyte level in flooded cells to fall below plate level
- Topping up with other than distilled or DM water
- Operating or storing the battery in too high or too low ambient temperatures
- Subjecting the battery to excessive vibration or shock

ESSENTIALS FOR BATTERIES:

- Long lifetime, high number of cycles at high level of discharge
- Low maintenance
- Suitable for operation under high temperatures
- Sizing based on operation conditions and DoD depending on expected lifetime

Table 1: Specification comparison between different battery types

Technology	Category	Temperature sensitivity (0C)	Environmental concern	Energy density (W/kg)	Efficiency (%)	Useful depth of discharge (%)	Life span (Cycles)	Self discharge (%/month)
Lead acid (LA)	Robust	(° –10/+50°C Requires hydrationC)	Gasing (H2), acid, toxic Pb	700	60 to 70%	50	400-800	5
Sealed LA (VRLA, GM, GEL)	Very robust	–10/+50°C	Toxic Pb	700	60 to 70%	50	600-1200	5
Ni-Cad (Nickel-Cadmium)	Very robust	–30/+60°C	Toxic Cd	1000	80%	80	1500-2000	Over 20
Ni-MH (Nickel-Metal-hydrate)	Robust	–20/+50°C	None	900	85%	80	800-1000	Over 30
Li-Ion (Lithium-Ion)	Sensitive	-10/+45°C Must not over-temp	Fire hazard	1500	90%	80	500-1000	2
Li-PO4 (Lithium Phosphate)	Robust	–20/+60°C	None	800	95%	80	2000	5
Ni-Fe	Very robust	–20/+45°C Requires hydration	Gassing (H2)	55	>90%	Over 90	n/a	20

THE BASICS OF A SOLAR THERMAL SYSTEM

The first solar collector dates back to the 18th century, but has not been used in a thermal system until the 20th century. Since then, the quality and efficiency have steadily been improved, but are still based on the same principle. A fluid (e.g. water) flows through the pipes, which are connected to an aluminium or copper plated absorber.

Figure 36: Solar thermal collector

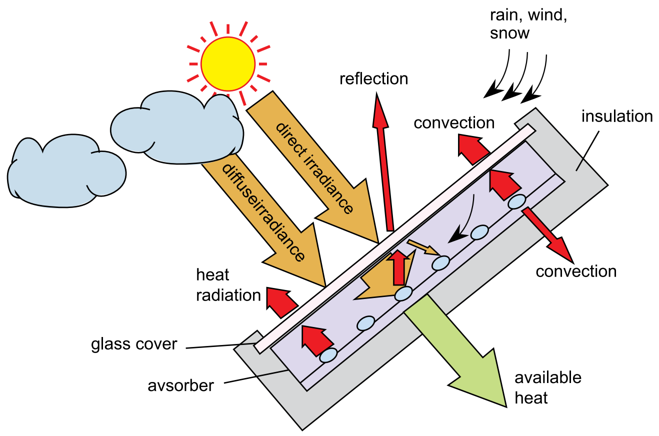

Figure 36: Principle of the thermal technology

The absorber is integrated into an insulated casing and covered by glass to avoid energy losses when exposed to heat. The hot water in the collectors is then transferred either directly, through storage tanks or heat exchangers to the energy consumer.

Solar thermal systems can reach a system efficiency of more than 50%, given suitable components and an accurate system design. Therefore, whenever heat is needed, a solar thermal is the more efficient technology compared to a solar power system. For instance, a solar thermal plant located at a global irradiation of 1,800 kWh/m² per year can generate 900 kWh/m² or more annually.

Thus, a standard collector sized at 2.5 m² generates at least 2,250 kW/h per year.

The space requirements for solar thermal systems depend on the type of installation.
For roof parallel installations a collector area of 2.5 m² is required plus a 10% additional mark-up for piping and walkways next to the collector areas. For flat roof installations, the required area needed depends on the shading effect between the collector rows. The shadow effect on flat roof installations can reach a 100% space mark-up of the collector area, compared to just 10% for roof parallel installations.

SOLAR THERMAL SYSTEMS CAN BE SEPARATED IN TWO DIFFERENT CATEGORIES:

1) Solar Water Heaters (SWH) or single systems:

Each energy consumer or small cluster of consumers is equipped with its own independent solar thermal system to provide the heat for the unit. A central control or piping is not necessary.

2) Central systems:

A solar thermal system with a centralized control, storage and heat transfer units, which is installed and connected to a centralized hot water system from where the heat is distributed to each energy consumer.

THE EFFICIENCY OF A SOLAR THERMAL SYSTEM DEPENDS ON THE FOLLOWING FACTORS:

- Efficiency of the collectors
- Design of collector areas
- Losses in piping and storage
- Operational conditions (e.g. temperatures)
- Project installation (orientation, inclination, and shading)
- Location
- Heat profile

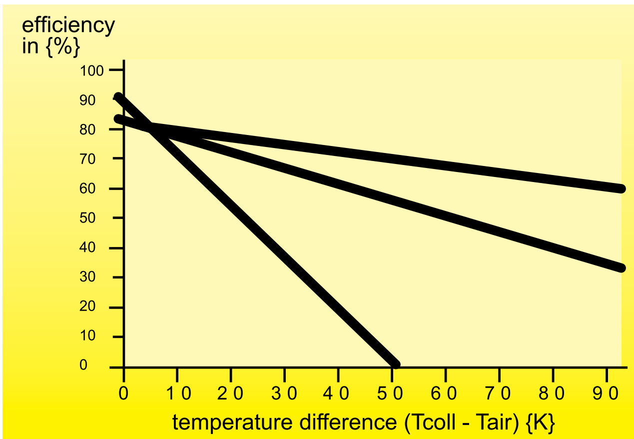

Figure 38: Collector efficiency for different types of collectors

The efficiency of a solar thermal system strongly depends on the ambient temperatures. Each collector type has its own characteristics, however the ambient temperature negatively affects the efficiency level of all types of collectors. As presented in figure 38, the lower the temperature of the collector, the higher the efficiency level of the system. 2.3

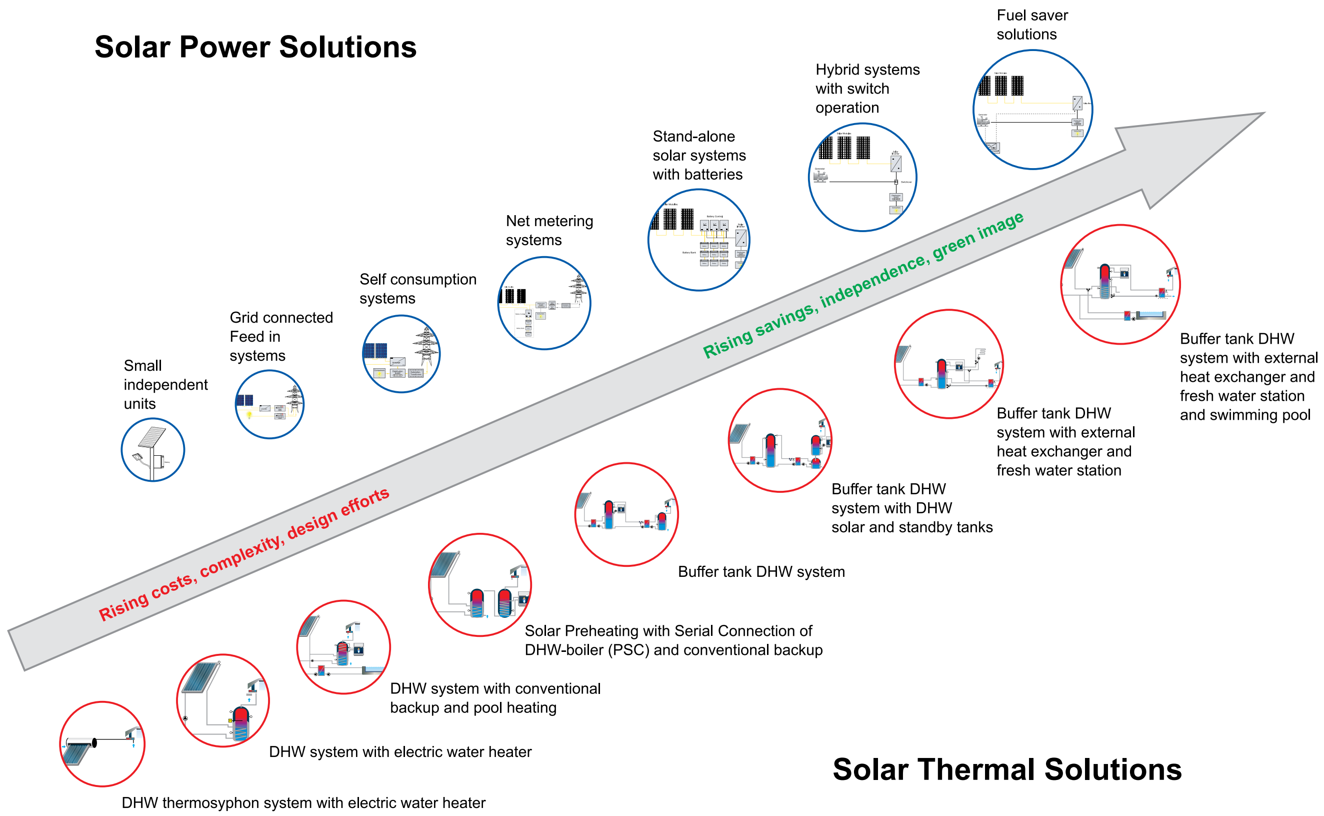

Figure 39: Solar Power – investment / solar grade line

1.3 POTENTIAL OF SOLAR ENERGY IN HOTELS

Hotels are considered one of the highest energy consumers in the building sector and are therefore responsible for large amounts of carbon dioxide emissions. The majority of the energy consumption is for water heating, general heating, cooling, as well as lighting. Therefore, the potential savings on energy for both heat and power are significant in the hotel sector, especially in geographical areas where solar irradiation is high.

SOLAR POWER

Solar power systems for hotels are similar to any other commercial or industrial application. There is no minimum or maximum solar power size, as the system depends on the available space, the hotel's architecture as well as the available budget. The first steps towards renewable energy can start with solar streetlights, gardening pumps or a small PV system in a range of 20-50 kW as a trial unit (e.g. a carport roof installation). A visible PV system as a decentralized smaller unit on a carport is also a great marketing tool to demonstrate the hotel's ambition to protect the environment.

The size of the system is irrelevant, as long as another energy source is available. It can support various applications within the hotel, where it is most convenient to connect the solar system to the main power source.

Even in cases of independent solar power solutions, such as water pumps for gardening, there are no specific design or size requirements to be followed. The energy consumer does not solely operate on solar energy, when the solar system is designed to transfer its energy to the internal grid from where it is then distributed to all connected devices.

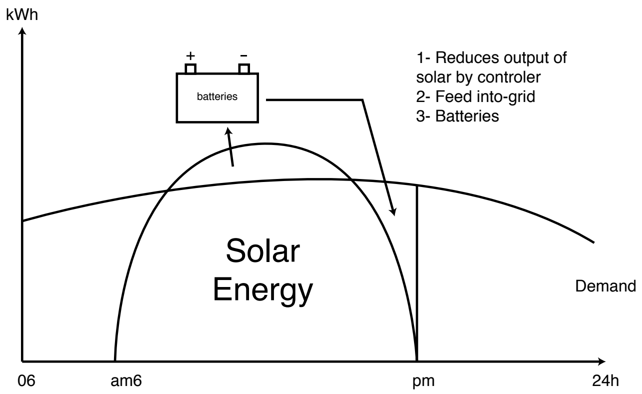

Figure 40: Ideal demand profile – good sunny season – high occupation, high demand

Figure 41: Carport solution

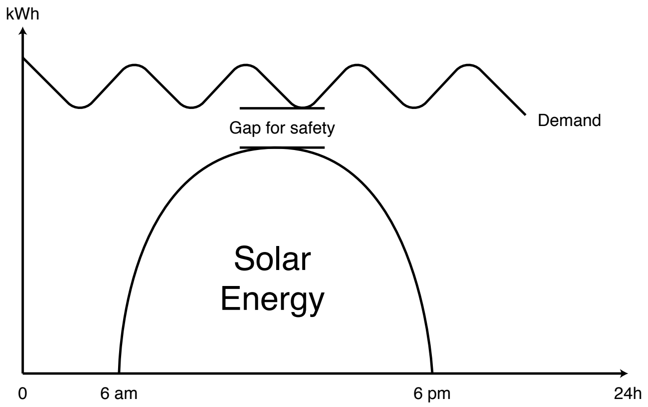

Figure 42: Demand > solar output

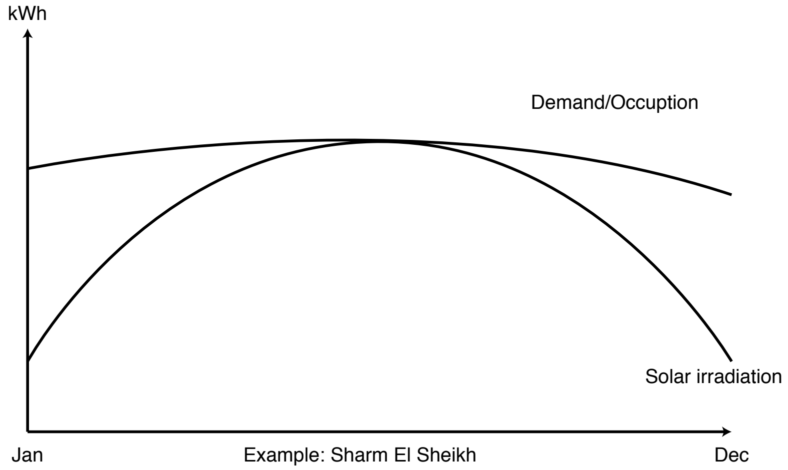

Figure 43: Solar power > demand – storage, reduction, etc.

The solar power systems can also be coupled to the mains or any sub-distribution board, as long as the safety device and board size are compatible with the size of the solar system. Due to the module structure of a PV system, it is possible to firstly start with a smaller application and expanding it at a later stage. In many cases, it is reasonable to primarily install a smaller system to gain first experience with the use of solar energy. However, even smaller units can yield significant cost savings. A small solar system with an additional electricity meter could record the real energy load profile of the hotel for a certain period of time (min. 1 hour), on which an expansion is based on. Having accurate data is crucial if the solar system is coupled with a battery bank.

For a grid-connected system, the sizing and integration of solar power into an existing power facility is simpler than including a solar thermal application. When the energy demand is consistently higher than the generated solar output, there is no conflict with any other power source (i.e. Diesel generators), as the solar system simply supports the existing power source. As a result, the solar support system assists in energy and cost savings for the hotel.

In the rare case of a power cut or unexpected low energy demand, control features can be implemented to coordinate operations with back-up generators or to reduce the solar output. However, for solar systems that closely serve the entire demand profile with the support of batteries or in case of an independent off-grid solution, accurate data is needed to design an optimal system. It is therefore easier to operate a solar application that aims to support an existing energy system.

Any solar system size helps to reduce the power consumption and energy costs. Even in cases of an oversized solar system, no negative consequences are caused. Through standard control systems, the solar energy output can be reduced to match the demand profile. Further, for systems located in a country with a feed-in place, excess solar energy can be transferred to the public grid under the feed-in tariff scheme.

SOLAR APPLICATIONS AS A SUPPORT SYSTEM HAVE TO BE DESIGNED TO ENSURE THAT:

1. Expected savings can be achieved
2. Supportive grid connection
3. Substations and distribution must fit the solar system
4. Safe operation and integration into existing grid
5. Control features in case of power cuts or other special conditions

BATTERY SYSTEMS HAVE TO BE DESIGNED TO ENSURE THAT:

1. During daytime enough solar energy is collected to satisfy daytime demand
2. During daytime enough energy is stored in batteries for non-sunshine hours
3. The lifetime of the batteries is not negatively influenced by repetitive charging and discharging cycles
4. Battery capacity is sufficient to satisfy night time demand
5. Safe operation and integration into grid
6. Control features to charge the batteries and/or to interact with other power sources

OFF-GRID SYSTEMS NORMALLY HAVE TO BE OVERSIZED TO ENSURE THAT:

1. During daytime enough solar energy is collected to satisfy daytime demand
2. During daytime enough energy is stored in batteries for non-sunshine hours
3. Aging effects of the system are calculated to ensure sufficient solar generation to satisfy demand across the system's lifetime
4. Operation with other power sources is smooth and controlled (e.g. efficiency of generators)
5. Control features to charge the batteries and/or to interact with other power sources

SOLAR HEAT

Hotels usually have an enormous demand for heat on a predictable level. Therefore, solar thermal energy has a long tradition in the hotel sector, as one of the best researched solar applications. The use of solar thermal started with traditional solar water heaters, which were often non-pressurized as open systems only working on

gravity and natural circulation.
Driven by research and development of new technologies such as pressurized systems from Central Europe, efficient storage, fresh water technologies and solar thermal systems are offering a wide range of possible solutions, which can be adapted to the requirements of any specific project.

Figure 44: SWH – open system

Figure 45: Central System

SOLAR THERMAL APPLICATIONS

HOT WATER CONSUMPTION

Solar thermal for hot water generation is the most common thermal application for domestic purposes and hotels. The required temperature level of 60-70°C is often sufficient and easily reached by efficient thermal collators. When considering a solar thermal system for hot water consumption, the required temperature and load profiles are important.

POSSIBLE APPLICATIONS ARE:

- Showers
- Swimming pools
- Wellness and spa facilities
- Laundry and kitchen
- Staff housing

Domestic hot water demand in private homes is nearly constant and very predictable over the year. Therefore, the design of a solar system only takes irradiation conditions and a constant energy demand into account. Usually the systems are designed to meet the demand in the months with good irradiation. In case of insufficient irradiation during colder months, the system serves only as supplementary support and a boiler serves as the main energy source.

It is important to note that the bigger the system size, the higher the solar fraction. However, generating excess heat from the solar system negatively influences the cost and system efficiency.

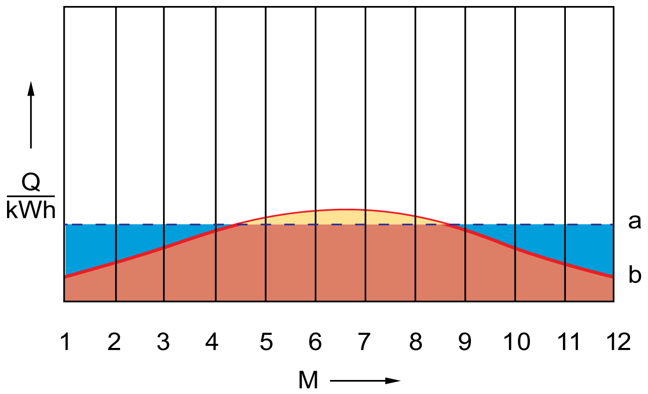

Figure 46: Demand profile and solar energy

EXCURSION 5

SOLAR FRACTION

Solar fraction = Solar Energy provided by the system / demand in %

Contrarily to domestic homes, in hotels the energy and hot water demand is highly dependent on seasons and short-time fluctuations according to the occupancy rate. It is essential to design the system based on accurate figures or valid assumptions to balance between costs and solar fraction according to the needs of the hotel. Oversizing is not always the best solution, as many times the solar system is most efficient when integrated as an alternative next to the main energy source and controlled by a management system, which regulates the usages of both. Regarding hot water systems, it is important to take not only the average daily hot water demand into account, but also the daily peaks, the time frame where most guests are consuming large amounts of hot water. The installed components must not only have enough storage capacity, but also heat transfer capacity to transmit solar generated heat on demand.

Hot water systems have to be designed
as follows:
a) Daily demand is covered under changing
occupancy rates
b) Daily maximum hot water demand has to be satisfied
c) No conflicts with existing boilers
d) Cover circulation losses
e) Ensure legionella protection and supply of hygienic
water

Figure 47: Storage tank with a fresh water station

POOL HEATING

Another interesting application for the use of solar energy in hotels is pool heating. The required temperature for pool heating is rather low, which increases the efficiency of the systems. Yet, hotel pools are generally not covered, leading to energy losses, especially during night time and at coastal areas with cold wind. Large collector areas are necessary to satisfy the daily energy demand to maintain the temperature in the pools constant.

Also for pool heating in hotels, the highest demand occurs during night time, when no solar energy is generated. An efficient solution is a solar hybrid application including a boiler or a combined heat and power system to realize solar efficient pool heating.

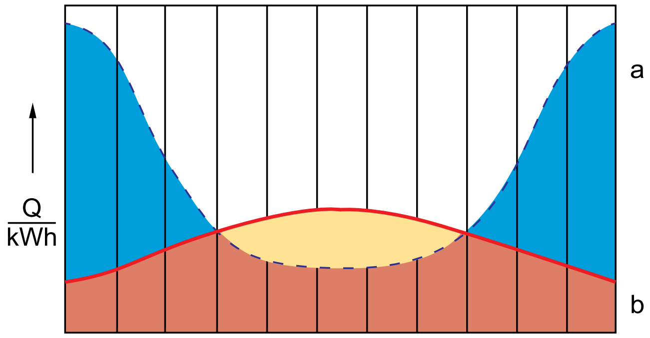

Figure 48: Heat demand of an outdoor pool and solar irradiation during the year

IMPORTANT: When designing a system for swimming pools, only use suitable materials that can withstand water with high chlorine content.

CIRCULATION LOSSES

All types of hotels and especially bungalows have complex and wide circulation systems to ensure immediate access to hot water on demand. The circulation systems account for more than 15% of the total energy demand and are a great opportunity for possible savings. The main issue is to install well-insulated pipes and a solar system that can cover the circulation losses and keep the temperature at a constant level. A simple heat transfer station that is connected to a solar storage tank heats up the return flow within the circulation up to the required level, without involving the boiler.

SPACE HEATING

During colder seasons many hotels require space heating. A solar system can support heating, when rather low temperatures are needed e.g. floor heating. However, solar energy is not suitable for conventional air heaters or radiators since the required temperature level is high and the demand is mainly at night or during sunset.

SOLAR COOLING

Solar cooling on the other hand is a technical versatile and reliable solution. Many conventional applications for solar cooling that are combined with adsorption filters or absorption chillers are already proven technologies. Yet, solar systems for solar cooling are not as cost-efficient in an acceptable time range compared to conventional energy sources. Therefore, solar cooling is mainly used in off-grid locations with perfect weather conditions that support the solar requirements most economically.

Regardless of the type of solar thermal application, it is impossible to meet the energy demand to a 100%. It is always necessary to implement a concept that includes a back-up system to satisfy the demand profile at all times.

Unless the hotel compromises with some fluctuations in temperature levels, it has to have a back-up energy system to balance the fluctuating temperatures due to varying irradiation. Nevertheless, for hotels located in areas with seasonal weather, the entire system must be able to cover the hot water demand independent from the solar system, in case of longer periods of bad weather.

For new projects the demand profile has to be estimated based on accurate calculations. Most preferably the system design should be based on already operational projects to meet the type and size of the system most precisely and to integrate a suitable back-up or supplementary system in order to achieve satisfying and efficient results.

The main challenge is to correctly size the system that takes fluctuations in the occupancy rate of the hotel into account and avoids under- or oversizing. Further the system size has to be well connected to the conventional energy system or back-up system. Solar thermal systems are usually never designed as complete self-sufficient systems without any conventional back-up. Only in remote locations with no access to any conventional energy source, a complete self-sufficient solar thermal system is reasonable. Hence, solar energy is most economic as a support system, with a flexible solar fraction depending on the available space and budget. However, solar fractions of up to 80 to 90% are realistic and economically feasible, especially in areas with 300 or more sunshine days a year. The aim is to achieve the highest possible solar fraction that results in the significant cost savings, whilst excess solar energy is reduced to the minimum to increase the efficiency of the system. If solar energy is generated, but cannot be used instantly, oversizing thermal systems can harm its components, due to high temperatures and pressures reducing the lifetime of the entire system. On the other hand, under-sizing also entails negative consequences.
In an under-sized system, the hotel frequently relies on the back-up system, which limits the energy savings, especially when inefficient boilers are used. As a result, a solar system – PV and thermal – has to be optimally sized.

According to thermal installations over the last few decades, the systems reached a lifetime of more than 20 years, with very little maintenance and operational costs. The lifetime of the system is also a question of initial investment for the hotel owners. Cheaper systems often have a shorter lifetime and may need to be replaced after several years. Low-cost solar water heaters often have a lifetime of less than 20 years.

WHAT CAN I DO, IF I AM PLANNING A NEW HOTEL?

Planning a new hotel facility offers many opportunities to integrate solar energy into the overall concept. This does not mean that all planned solar applications have to be integrated in the initial plan of the hotel. The path toward a fully renewable energy driven and independent hotel can be a step-by-step approach over a longer period of time.

In established hotels it is necessary to work with existing structures and applications, such as existing boilers, generators, pumps and other devices, which may lack efficiency. Contrarily, in a new hotel, the energy demand should be designed in the most efficient manner possible by using energy-saving technologies (e.g. LED lighting, water saving devices). Thereafter, solar applications should be integrated as either a supportive or self-sufficient system to save costs. Each kWh that can be saved on the demand side reduces the investment for a solar system.

There are various possibilities to implement a solar system into a new or an existing hotel. When installing a hybrid and/or back-up solution with an overall control and monitoring system at a new hotel, initial investment and operational costs for different options and solar fractions can be compared. For existing facilities, however, conventional energy systems, landscaping, and the hotel's architecture add some constraints to the possibilities for a solar system. Nevertheless, economic and cost-saving solutions are possible in both cases.

For off-grid applications solar energy offers the chance to keep energy costs low and stable by integrating solar energy into a flexible hybrid concept with conventional generators or in combination with heat and power units.

ASPECTS TO TAKE INTO ACCOUNT WHEN INTEGRATING A SOLAR SYSTEM INTO A NEW HOTEL:

- Use energy efficient technologies on the demand side
- Take the total costs of ownership of these components into account, having in mind, that for many components the initial investment is low compared to the total lifecycle costs (e.g. for light, pumps, motors etc.)
- Reduce energy consumption by energy efficient building technologies, such as active shading, high glass qualities and proper room insulation
- Use maximum possible natural light and ventilation
- Use control technologies to avoid waste of energy (e.g. movement sensors for light, AC or light intensity sensors)
- Use water saving devices and technologies (e.g. timed shower system)
- Use automatic mixing valves to limit temperatures at the shower heads while adjusting temperatures to reduce waste of water and hot water demand
- First increase energy efficiency, then integrate solar energy systems
- Design roofs suitable for solar panel installations according to needed inclination and limited shading
- Prepare a detailed demand profile and try to avoid peak demand by shifting certain activities (e.g. laundry) to times with lower energy demand, while trying to include most activities during sunshine hours
- Integrate solar panels into functional areas, such as carports, or as shading elements
- Prepare space and spare connections in the main distribution board
- Install wiring for later connections of additional solar systems
- Install accurate water and power meters to allow monitoring of daily energy consumption to optimize the system and to collect data for future solar expansions
- Make solar systems visible to guests as a marketing tool
- Prefer flexible and efficient generator solutions in off-grid applications and locations where frequent power cuts are expected
- Use flexible generator cascades in off-grid applications to allow efficient control and operation
- Use generators with a wide frequency range of high efficiency and possibility for external control
- Make an overall heat and power concept and check the possibility to integrate a solar system combining heat and power – thermal and PV

Solar thermal systems for hot water are efficient and cost-effective. Especially in the design phase of a new hotel, a solar thermal system in combination with a conventional energy back-up is easy to integrate and economically feasible to provide sufficient and stable hot water supply yearlong. Regarding off-grid applications, solar power can be the main energy source together with either batteries and/or generators to secure energy supply during night time. For any other hotel that is grid-connected, a solar power system as a supportive solution contributes to energy cost-savings. PV panels can be integrated on a step-by-step approach increasing the solar fraction over time to ease the initial investment and to gain first hand experience before relying fully on a renewable hybrid solution.

WHAT CAN I DO IN MY EXISTING HOTEL?

Existing hotels often have to compromise when integrating solar energy or any other additional energy sources. Usually available boilers and generators are not replaced and the solar system has to be synced with the existing devices, which is not always the most optimal solution. Nevertheless, established hotels have the advantage of existing data of the demand profile for heat and power, which allows the solar system to be accurately designed to serve the actual needs of the hotel. In general, in any hotel – existing or planned – a cost-efficient solar energy solution can be integrated, once the energy demand of the hotel is identified. The initial step towards an economic solution is to ensure energy efficiency before investing into an additional energy source. A lower demand profile demands a smaller solar system, hence a smaller investment.

ASPECTS TO TAKE INTO ACCOUNT WHEN INTEGRATING A SOLAR SYSTEM INTO AN EXISTING HOTEL:

- Replace old, inefficient devices by energy efficient technologies to lower the demand profile
- Take total cost of ownership of the components into account when deciding to replace or maintain existing devises
- Reduce the energy demand by adding energy efficient building technologies, such as active shading and insulation
- Use control technologies to avoid energy waste (e.g. movement sensors for light, AC or light intensity sensors)
- Use water saving devices and technologies (e.g. timed shower system)
- Use automatic mixing valves to limit temperatures at the shower heads while adjusting temperatures to reduce water waste and hot water demand
- Check if the insulation of the hot water circulation lines needs replacement to reduce losses
- Check available roof spaces for installation of solar systems
- Prepare a detailed demand profile and try to avoid peak demand by shifting certain activities (e.g. laundry) to times with lower energy demand, while trying to include most activities during sunshine hours
- If no accurate energy demand data is available, install accurate water and power meters to monitor daily demand to optimize and integrate solar energy systems
- Check if the existing generators have a wide frequency range of high efficiency and possibility for external control

For cost-efficient integration of solar energy in hotels, the first step should be a solar thermal system to reduce the electricity costs for hot water and circulation significantly. If space is available on e.g. roofs or carports, then solar power is the second step towards a sustainable energy mix. The transition towards renewable energy can be a gradual approach with thermal as a first step and PV as the second.

IS SOLAR ENERGY ECONOMIC?

Whether the use of solar energy is economic for hotels depends on several factors. For hotels with an existing connection to the public grid, solar energy takes on the role of a supplementary energy source to reduce the dependence on energy supplies at fluctuating energy prices and to lower energy costs. In case of hotels located in areas with unreliable power supply, the solar system with a battery or generator as a back-up solution allows independent energy in times of power shortages.
For hotels without access to the public grid, solar energy off-grid systems may be the only reliable, clean and stable solution. To supply the needed energy in remote areas with Diesel generators is costly and unstable. Their high maintenance, pollution and fluctuating Diesel prices are among others, consequences hotels encounter when fully relying on Diesel generators. Thus, solar energy is a great alternative for hotels in off-grid areas.
Solar thermal applications usually operate in combination with a conventional energy system. A solar thermal system as an alternative energy source for the hotel is very cost-effective as it does not only reduce reduces the energy costs by using the solar technology, but also lowers the energy consumption by minimizing the losses of the entire system. The exact cost savings resulting from the integration of a solar system – PV or thermal – has to be calculated for each specific project.

THE FOLLOWING SEVEN FACTORS INFLUENCE

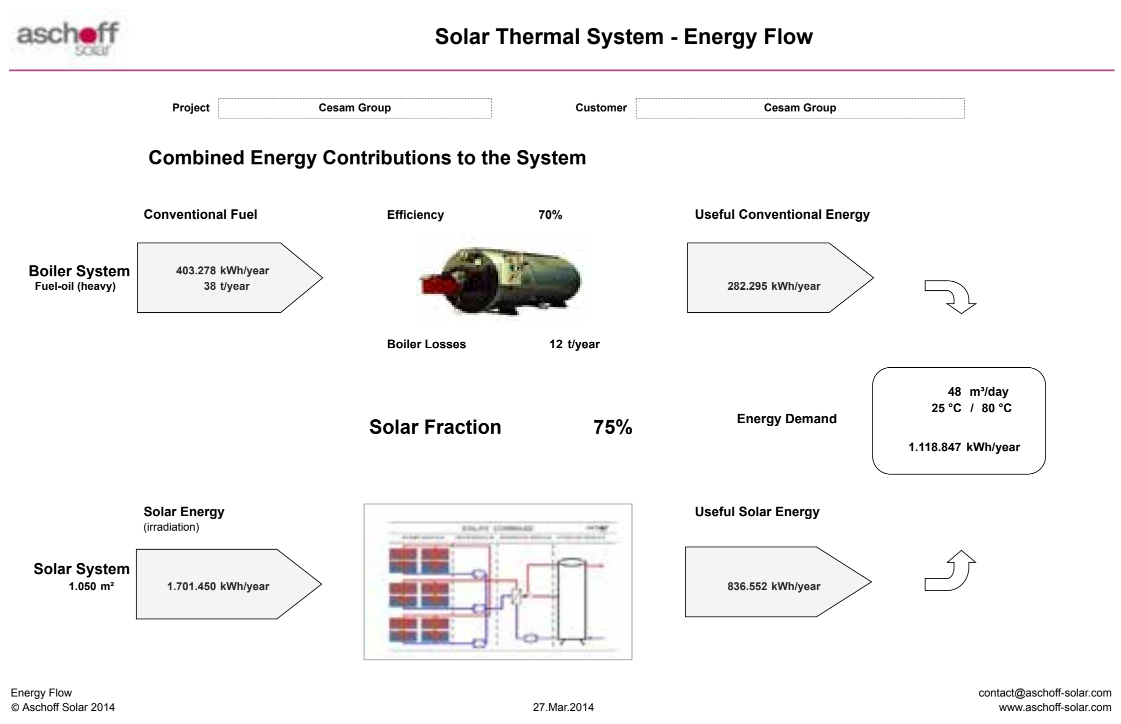

Figure 49: Energy flow of a solar thermal system

Project Amortization for Solar Power System

Project:	**Ocean View Hotel**	**Location:** El Gouna, Egypt			
System type:	Self-Consumption	**degradation**	0,80 % p.a.		
System Power	30 kW	**specific solar yield:**	1750 kWh/kWp p.a.	**operational costs:**	0,2 % of invest
Energy Price (Tarif Mix):	0,11 EUR/kWh	**energy price increase:**	15% p.a.	**investment:**	47.400,00 €

year of operation	1	2	3	4	5	6	7	8	9	10
solar yield kWh/a	52.500	52.080	51.663	51.250	50.840	50.433	50.030	49.630	49.233	48.839
accumulated solar energy kWh	52.500	104.580	156.243	207.493	258.333	308.767	358.797	408.426	457.659	506.498
energy price in EUR/kWh	0,11	0,13	0,15	0,17	0,19	0,22	0,25	0,29	0,34	0,39
savings in EUR	5.775	6.588	7.516	8.574	9.781	11.158	12.729	14.522	16.566	18.899
operational costs in EUR	95	95	95	95	95	95	95	95	95	95
accumulated savings in EUR	5.680	12.174	19.594	28.074	37.760	48.823	61.458	75.885	92.357	111.161
account balance in EUR	-41.720	-35.226	-27.806	-19.326	-9.640	1.423	14.058	28.485	44.957	63.761

year of operation	11	12	13	14	15	16	17	18	19	20
solar yield kWh/a	48.448	48.060	47.676	47.295	46.916	46.541	46.169	45.799	45.433	45.069
accumulated solar energy kWh	554.946	603.006	650.682	697.977	744.893	791.434	837.602	883.401	928.834	973.903
energy price in EUR/kWh	0,45	0,51	0,59	0,68	0,78	0,90	1,03	1,18	1,36	1,57
savings in EUR	21.560	24.596	28.059	32.009	36.516	41.658	47.523	54.214	61.848	70.556
operational costs in EUR	95	95	95	95	95	95	95	95	95	95
accumulated savings in EUR	132.626	157.127	185.090	217.005	253.426	295.084	342.607	396.821	458.669	529.225
account balance in EUR	85.226	109.727	137.690	169.605	206.026	247.684	295.207	349.421	411.269	481.825

year of operation	21	22	23	24	25
solar yield kWh/a	44.709	44.351	43.996	43.644	43.295
accumulated solar energy kWh	1.018.612	1.062.963	1.106.960	1.150.604	1.193.899
energy price in EUR/kWh	1,80	2,07	2,38	2,74	3,15
savings in EUR	80.490	91.823	104.752	119.501	136.327
operational costs in EUR	95	95	95	95	95
accumulated savings in EUR	609.715	701.538	806.290	925.790	1.062.117
account balance in EUR	562.315	654.138	758.890	878.390	1.014.717

Return of Investment: 5,8 years

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Figure 50: Calculation scheme for cost-efficiency of solar power system

THE COST-EFFICIENCY OF A SOLAR ENERGY SYSTEM:

1. Solar yield

The expected solar yield of a solar system should be calculated by using professional design tools like PV-Sol for solar power or T-Sol, Polysun for solar thermal. These software programmes use accurate weather data to simulate any solar project according to the location's weather conditions. It includes all aspects influencing the energy output of the systems including the components, orientation and needed inclination. The software provides the information of the daily and yearly solar yield profiles and possible savings. The solar yield profiles can then be compared to the total energy demand profile to evaluate the solar system design and cost efficiency.

2. Energy savings (in kWh or saved fuel in l/year)

The energy savings for solar power is equal to the solar yield, if the hotel is connected to the public grid and the solar capacity is not larger than the energy demand. In case the solar output surpasses the energy demand, solar energy excess has to be either transferred back into the grid for a profit under a feed-in tariff or stored. The compensation for feeding the excess solar power back into the public grid has to be added to the cost-savings of the system.

For off-grid situations, the efficiency of the Diesel generators influences the cost-saving calculation. The savings are equal to solar yield/efficiency of the power generation (approx. 25-35%). Thus, any kWh of solar energy saves 3-4 times energy on the fuel side, if no CHP (combined heat and power generation) is used.

For solar thermal it is more complex to calculate the savings. The efficiency of the conventional hot water system e.g. a boiler has to be taken into account. If the solar system provides for instance 100,000 kWh per year and the overall efficiency of the boiler system is 70%, the savings can be calculated as follows:

Savings in kWh = Solar yield in kWh/efficiency of conventional system in %

Savings = 100,000kWh per year/0.7 = 142,857 kWh/year

Hence, for solar thermal, the savings are usually higher compared to the generated energy. The lower the efficiency of the conventional energy system, the more valuable is the solar thermal application.

3. Electricity price, storage costs and transportation

The higher the electricity or fuel price, the higher the savings of the solar system and the shorter the payback time of the investment. For electricity from the public grid, the costs can be calculated according to the monthly energy bills of the utility. For solar power off-grid applications, the calculation of electricity costs must take the overall efficiency of generators into account, as well as any additional costs, such as transportation, fuel storage as well as maintenance and operational costs for the generators or other devices. For solar thermal applications, the cost savings are influenced by the fuel costs, its transportation, and storage as well as by the reduction of maintenance costs and efficiency gains compared to the conventional system.

4. Future outlook on electricity surcharges

The future outlook of rising energy costs for fuel or electricity has a significant influence on the cost efficiency of any renewable energy system. PV or thermal systems are installed for a lifetime of at least 20 years. Therefore, the correct calculations have to reflect the energy price increases in the future for the next 20 years, if possible.
Assumptions on energy prices, especially short-term predictions, are rather difficult. However, energy price estimates are available through the World Bank Group or the International Energy Agency, which both anticipate increasing energy prices, despite the current low oil price. Therefore, an average of 12-15% annual increase in electricity prices is viewed as realistic. In countries where electricity is subsidies an even higher surcharge is expected.

5. The cost of financing

The financing of a solar energy system is important. The loan's interest is in some cases secondary, as the access to finance per see is difficult and the duration often too short. A long-term loan of approx. 10 years that replicates the payback period of a solar system should be targeted in order to ease the working capital and to maintain the attractiveness of the investment.

6. Operation and maintenance costs

The operations and maintenance costs for solar systems, especially solar power systems, are quite low compared to any conventional energy source. According to European standards (e.g. VDI2067) and experiences of installed system over the past decades, predict a reasonable figure for operation and maintenance to be between 0.2-0.5% of the total investment per year.

7. Pay-back period and profit rate

In general, solar systems are cost-efficient, due to the proven lifetime of approx. 25 years with payback periods of up to 10 years. Once return on investment is met, the systems are generating profits, with minimal operation and maintenance costs, given the appropriate usage of the systems.

1.4 HOTEL TYPES AND SOLAR ENERGY

Hotels can be split into different categories, according to the type of building and usage. The hotel type has a direct impact on the possibilities for the use of solar energy.

HOTEL TYPES:

- Bungalows
- Apartment buildings
- High-rise buildings
- High comfort resorts for individual travellers or all-inclusive packages
- On-grid or off-grid
- Small unit or large hotel complex

BUNGALOW HOTEL

The bungalow hotel with small, single or double bedroom cabins are next to the high-rise buildings, one of the most challenging types of hotels for the integration of solar energy (figure 51. If the units are equipped with individual, electricity-based hot water systems, e.g. instantaneous water heaters, the only option for solar thermal systems is the solar water heater. However, in case the bungalows have a thatched roof, the integration is technically possible, but might disturb the customers' aesthetic expectation.

Regarding solar power, the small available space on the roofs hinders the integration of solar power panels at each bungalow. In such cases a central system at a facility, such as staff housing or main restaurant buildings can be realized with the use of micro inverters, which convert the DC into AC power directly at the modules, which can be connected to any AC connection within the system.

If several units can be combined into a cluster, it is possible to realize small, pressurized systems with a common solar buffer storage to provide hot water for all independent bungalow units. The design factors for contemporaneity of demand and size of the system are then minimized, which is easiest for newly planned hotels.
Most bungalow hotels have a central hot water circulation system that is connected to each bungalow, which distributes hot water on demand. The integration of a solar solution to the central hot water system is quite simple. It is crucial to verify the energy losses in the circulation system as well as its operating time, to analyse if losses can be reduced and the system optimized, before a new solar application is implemented.

SOLAR ENERGY POSSIBILITIES FOR BUNGALOW HOTELS:

- Solar water heaters for single units
- Solar water heaters or pressurized system for unit clusters
- Centralized solar thermal system in case of central heating and circulation
- Panels with micro-inverters on single units
- Centralized solar power system on facilities (e.g. restaurant, laundry, staff housing)
- Solar power panels on carports
- Solar street lights and outdoor lighting
- Solar pumps for gardening

Figure 51: Bungalow hotel

Figure 52: Apartment type hotels

APARTMENT HOTELS

Apartment hotels offer the best conditions for the integration of solar energy systems. The structure and ratio between guest rooms and available space on the roofs allow the implementation of a solar system to supply the needed energy and hot water demand. The distances between the solar system and the consumer is often quite short and even in cases of longer stretched buildings, the hotel complex can be split into several units, which are supplied by multiple independent solar systems, reducing the circulation losses to a minimum.

The main obstacle for some apartment hotels is the technical equipment and piping on the roofs. Before installing the solar system, all applications on the roof have to be rearranged. Yet, an advantage is that the solar panels create additional savings by providing shade to equipment, which is more effective when not directly exposed to sunlight (e.g. cooling units of air-condition) or are sensitive against UV irradiation (e.g. wires, PP pipes and insulation).

SOLAR ENERGY POSSIBILITIES FOR APARTMENT HOTELS:

- Solar water heaters or pressurized system for unit clusters
- Centralized solar thermal system in case of central heating and circulation
- Decentralized solar power systems connected to sub-distribution boards
- Centralized solar power system on facilities (e.g. restaurant, laundry, staff housing)
- Solar power on carports
- Solar street lights and outdoor lighting
- Solar pumps for gardening

HIGH-RISE HOTELS

On high-rise buildings the available space on the roof is often insufficient for solar energy applications (figure 53). The distances between the rooms from the highest to the lowest level is too long to achieve a significant solar fraction for high-rise buildings. However, it is possible to install PV panels on the façade of the buildings at a lower efficiency. The solar PV modules or thermal collectors can then be implemented as integrated building systems or as shading elements. Another challenge for high-rise buildings, especially in urban areas, is the shading effect by other buildings close to the hotel. A cost-effective solution is the façade-integrated solar systems that substitute other expensive materials with active solar surfaces. Façade integrated solutions are possible for both, solar power and thermal. However, the lower efficiency of collectors and panels has to be taken into account, as the vertical inclination is not optimal. The solar thermal façade-installation can be improved by using evacuated tube collectors with horizontal tubes. For solar power, special thin-film modules are a feasible solution, which have a higher efficiency under suboptimal inclination.

Figure 53: High-rise hotels

SOLAR ENERGY POSSIBILITIES FOR HIGH-RISE HOTELS:

- Centralized solar thermal system or solar power system roof installations to cover partial demand
- Façade integrated solar power system as a replacement of conventional façade materials
- Solar thermal balcony systems

HIGH-LEVEL HOTELS FOR INDIVIDUAL TRAVELLERS

Solar energy is essential for high-level hotels serving guests with exclusive quality expectations towards comfort standards, sustainability and service reliability. Especially in eco-lodges, clean energy should be visible to the customers, as awareness and sensitivity towards protecting the environment is continuously raising and many hotel guest wish to lower their personal carbon footprint during their guests vacations. This is valid for all kinds of hotels in this segment, regardless of their size and facilities.

Figure 54: Shaded sun terrace with semi transparent PV modules

SOLAR ENERGY POSSIBILITIES FOR HIGH-LEVEL HOTELS FOR INDIVIDUAL TRAVELLERS:

- Advertise the use of solar energy
- Use innovative and special technologies, such as coloured thin-film modules
- Integrate solar energy in form of sun terraces with semi transparent modules or carports
- Offer e-mobility solutions powered by solar operated motorcycles or golf carts

ALL-INCLUSIVE HOTEL RESORTS

In particular, large all-inclusive hotels have to ensure a stable cost-efficiency ratio. When deciding for a solar energy system, the primary aim is to design the most economic solution to keep the running costs at a minimum. Most all-inclusive hotels depend strongly on the holiday seasons, resulting in fluctuating energy costs according to the occupancy rates. Solar energy is a great alternative to maintain predictable energy costs, even in low seasons. Economically, the solar output should not exceed the energy demand of the low season (minimum demand), in order to avoid solar excess, which cannot be stored or fed back into the public grid, lowering the efficiency of the system. In all-inclusive hotels, solar energy is best to cover the fixed energy demand, regardless of the occupancy rate.

SOLAR ENERGY POSSIBILITIES FOR ALL-INCLUSIVE HOTELS:

- Replace inefficient outdoor lighting with solar powered units
- Centralized solar thermal systems to save fuel costs
- Centralized solar power systems according to fixed demand
- Install solar systems independent from the occupancy rate with the primary aim to reduce fixed energy costs

ON-GRID OR OFF-GRID?

ON-GRID

The best starting position for a solar system are hotels connected to the public grid. As long as the grid is stable and power cuts are rare, the budget and expected energy savings depict the size of the solar system. In a grid-connected system, solar thermal applications can operate on existing power supply, whereas solar excess from solar power can be transferred back into the public grid, avoiding the need for cost-intensive battery solutions. Hence, sizing for a solar system supporting an on-grid hotel is not as sensitive compared to off-grid resorts.

OFF-GRID

Camps and hotels without a grid connection, away from any stable power source, solar energy is one of the most economic and viable energy solution. However, off-grid applications need to be sized accurately and in many cases need to be oversized to ensure sufficient electricity also in the future. Nevertheless, an off-grid solar system can be more beneficial compared to conventional energy sources, such as Diesel generators. Fluctuating Diesel prices, fuel transport, storage, and costly operating expenses are valid factors favouring a cleaner and stable energy solution based on solar technology.

Solar thermal installations for off-grid applications require a secure power supply for the control of the system. Only a basic thermosiphon system can operate completely without electricity, yet at a lower performance. For off-grid applications where solar energy is the only source of electricity, it is important to oversize the system to calculate for aging effects, which lower the systems performance over time. Excess solar energy in the beginning is expected to cover the aging effect in the long-term to ensure sufficient power supply in the future. When including batteries in the system design, their logistics in terms of fast exchange are essential. The lifetime of batteries is much shorter compared to the one of the solar system, and therefore their exchange has to be secured to guarantee the performance of the system design at all times.

SOLAR ENERGY POSSIBILITIES FOR ON-GRID HOTELS:

- No limitations
- Size according to budget and energy saving expectations
- Request to feed-in or net-meter excess solar energy if applicable

SOLAR ENERGY POSSIBILITIES FOR OFF-GRID HOTELS:

- Reduce energy consumption through independent solar lights and gardening pumps
- Integrate solar power into the entire energy concept including back-up or supplementary generators and batteries for reducing maximum demand and smoothen operation
- Reduce water demand before installing a solar thermal system
- Use most efficient technologies available to reduce overall energy onsumption

FOR SOLAR THERMAL ONLY:

- Include enough buffer capacity to balance fluctuating occupancy rates

SMALL HOTELS

Figure 55: Off-grid Camp in Sinai, Egypt

The hotel size has a significant influence on the cost-efficiency of a solar energy system. Especially for centralized solar thermal systems, some fixed costs for control and safety devices must be covered, regardless of the system size. For smaller hotels with a hot water demand of less then 10,000 l/day, the costs for a centralized solar thermal system are quite high. Instead, it can be more beneficial to install a combination of several independent solar water heaters (figure 55). As an alternative to the regular solar water heater, is the European system for domestic hot water supply, which provides hot water at a higher comfort to the guest of the hotel.

For solar power, fixed costs for basic components such as sensing, control device or AC connections are minor compared to solar thermal applications. Although, for very small systems of up to 20-30 kWp, the fixed costs are proportionately larger than for bigger sized applications. Yet, rooftop solar systems are a great way to reduce energy costs even for small hotels. The lower energy consumption facilitates the realization of an optimal and profitable back-up solution.

SOLAR ENERGY POSSIBILITIES FOR SMALL HOTELS:

Figure 56: Multi-Solar Water Heater system for smaller hotels

- Reduce hot water demand by water saving devices and temperature limitation
- Reduce energy consumption through efficient lighting and air-condition technology
- If roof space is limited, prioritize solar thermal over solar power system
- Implement a solar power system to cover the fixed energy consumption (i.e. base load)

LARGE HOTELS

Larger hotels with a capacity of several hundred rooms are best served with an economic solar solution that is centralized to leverage on the positive scale effect with respect to system costs and demand structures of different consumers (e.g. service area, pool, guests, spa etc.). The solar system can be structured according to the load profile of each consumer, in which the generated solar energy can be transferred from a main distribution board to all connected consumers. Larger hotels also have the advantage that the demand is usually not evenly spread across all rooms at all times, resulting in a smaller real consumption rate. Thus, the capacity of the solar system per room can be sized smaller than its nominal capacity. However, the disadvantage of larger hotel units is the existing heat generation and distribution system, which is complex and entails long circulation lines as well as higher volatility in occupancy, compared to smaller units.

SOLAR ENERGY POSSIBILITIES FOR LARGE HOTELS:

- Optimize hot water system and circulation prior to installation of a solar thermal system
- Reduce water demand by using water saving devices and temperature limitations
- Reduce energy consumption through efficient lighting and air-condition technology
- Install efficient alternatives for outdoor lighting (e.g. golf and pool areas)
- Replace shading material with solar power panels (e.g. roof for carports, laundry, kitchen, staff housing etc.)

Figure 57: Large hotel unit in Hurghada, Egypt

1.5 ARCHITECTURAL INTEGRATION

The appearance of a hotel is important for the comfort of its guests. A visually pleasant integration of the hotel's technical appliances with its architecture is crucial. In particular for hotels away from the public grid or with insufficient electricity coverage, a dependence on bulky and noisy Diesel generators disturbs the hotel's landscape and guests' experience. Solar energy systems however are an economic and secure alternative energy source that positively adds to the appearance of the hotel's architecture. Solar panels can be integrated to the hotel's surrounding landscape, complimenting to an environment-friendly philosophy, regardless of the size of the hotel and its energy demand. The main constraint for solar energy is the available space to install the solar systems. The larger the electricity coverage through solar power, the more space is needed. Yet, there are various smart system designs available to achieve the optimal solar energy generation, yet space saving solution for any hotel architecture, whether they are small bungalows or large five-start hotel resorts.

REDUCING THE VISIBILITY OF SOLAR SYSTEMS

Not every hotel resort wishes to display the installed solar systems. There are various alternatives to use solar energy without a visual impact to the hotel's appearance. System installations on free fields, staff housing or other facilities away from the hotel rooms and main entrances are options to avoid the direct visibility of the systems. This is particularly simple for hotels with a flat roof, where solar power or thermal panels can be installed without any inclination using standard support structures based on ballasting as seen in the picture below (figure 58). However, when installing the solar system further away from where the energy is needed, it is important to design the system with appropriate wires and cables connecting the solar system to the energy outlets. For solar thermal systems the focus is on the insulation of piping to keep system losses within the acceptable range.

Figure 58: Hidden solar thermal system on an apartment hotel

Figure 59: Hidden solar power system

SYSTEM INTEGRATION

Integrating a solar system into the architectural concept of a newly planned hotel resort is the easiest approach. Solar panels take part of the buildings' design and space is created closest to where energy is demanded (e.g. hotel rooms, spa facilities), in order to minimize energy losses through excess wiring. For existing hotels with already placed landscaping, it is a little more challenging to integrate a solar system, particularly when the aim is to minimize the visibility of the panels. Yet, additional benefits can be gained through the use of solar active surfaces and shading for air-conditioning units. To facilitate the integration of solar power into the hotel's façade or roofs, coloured solar panels are an option, if the standard blue or black modules disturb the imagine of the hotel's design. These panels are available in multiple colours, but at a higher cost compared to the standard modules (figure 60).

The customary installation of solar power or thermal systems is to install the system on an available flat or pitch roof using a standardized support structure with an optimal inclination of the modules to achieve the most efficient installation (figure 61).

Figure 60: Coloured thin-film PV modules

Figure 61: flat roof installation of a solar thermal system

Figure 62: Integrated solar power system on a apartment hotel

Figure 63: Solar thermal system as a highlight in front of the hotel

Environment-friendly tourism is increasing in importance for many guests worldwide. A great way to highlight the use of clean and sustainable energy is to install the solar systems at the elevation view of the main hotel buildings. The solar systems not only serve as an alternative energy source, but also add to the hotel's image for taking responsibility toward climate change. Thus, satisfying the expectation of many guests concerned with greener and more sustainable tourism.

SPECIAL SOLUTIONS

If no suitable roof areas are available within and around the hotel resort, the solar system can serve as an additional function and replace conventional roof on carports, greenhouses, shelters or decorative elements, such as semi-transparent covers for shading on rooftop terraces.

OPEN AREA INSTALLATIONS

Hotels in remote or rural areas where excess space is available, it is often the most economic way to install the solar power and thermal systems in an open area, especially if it's a large system covering a major part of the energy consumption (picture 59). When installing on an open field next to the hotel facilities, the solar system has to be connected to the heat and power centre via appropriate piping and wiring.

No matter what system design, it is essential to use only qualified components for the support structure, which ensures long and safe operations for decades, especially in geographical areas along the coast with temporary high wind loads.

The installation of a solar thermal system requires various factors to be taken into account that have an effect on the size and the hydraulic of the system. In the following section each factor is explained in detail for the system provider and the hotelier to design their thermal application accordingly.

1.6 CHALLENGE FOR HOTELS

HOTEL ENERGY DEMAND AND SYSTEM CAPACITY

Requirements for the dimensioning of the collector system are based on the average room occupancy and energy demand of the hotel. Depending on the location, the peak energy demand varies across the year. The higher the load in the summer months, the more solar energy can be used for water heating. For a tourist accommodation, the average daily consumption per guest has a fixed size. It results from the ratio of the total daily usage of the accommodation times the number of occupied beds. The total consumption is therefore solely dependent on the occupancy rate of the hotel. The warm water demand will be further explained in chapter 4, section 3.
The daily consumption characteristics and peak demand for hot water depends on the hotels consumption and facilities offered (e.g. spa and wellness facilities). The term 'consumption characteristics' includes the different consumption patterns that are considered when designing a solar-assisted hot water system. These include the daily, weekly and yearly water profiles.

For the dimensioning of the collector and the solar storage tank, accurate data on the annual or weekly demand is important. In contrast, for the standby cylinder the daily profile entailing maximum expected peak hours is crucial. The standby memory and the back-up security of hot water supply have to be designed that the maximum peak demand is satisfied. The precise course of the daily water consumptions is not in the forefront, but rather the maximum peak demand at full capacity of the accommodation. Studies have shown that it is sufficient that the tap profile is hourly based.

Figure 64: Solar system as a crown on top of a high-rise hotel

Figure 65: Carport installation

Figure 66: Open area solar power system

Figure 67: Open area solar system – integrated into the landscape

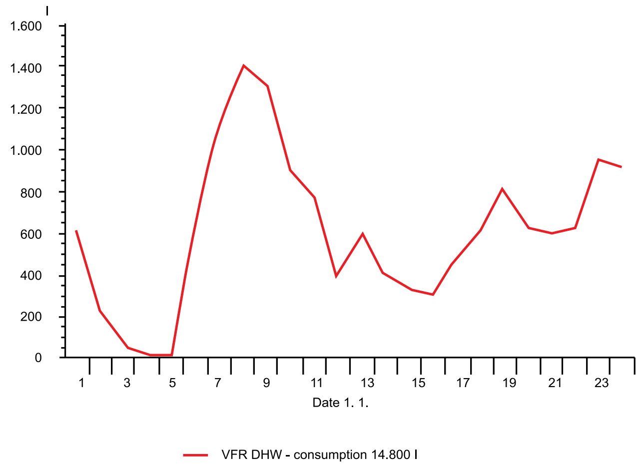


Figure 68: Daily profile of a city hotel

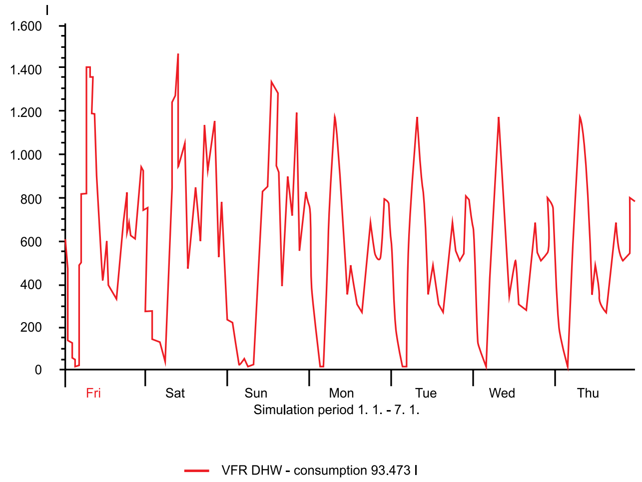


Figure 69: Weekly profile of a city hotel

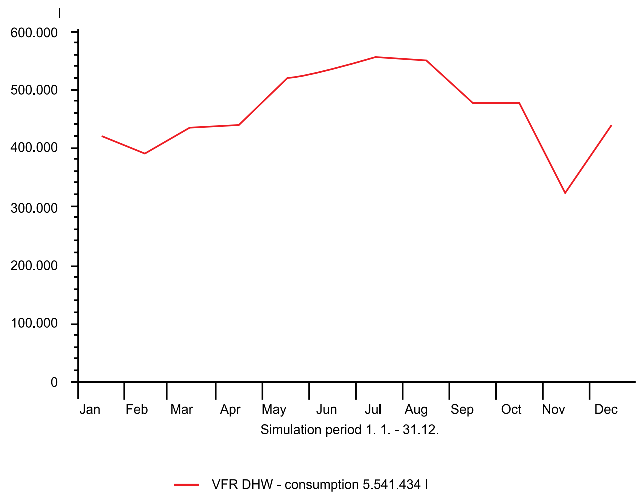


Figure 70: Yearly profile of a city hotel

Nearly all accommodation types have a morning peak between 7 and 8 am. Within this period about 20% of the total daily requirement is tapped. Also most hotels have an evening peak that is less pronounced compared to the morning peak. The consumption peak during the evening is not as high, but the demand for warm water lasts longer than in the mornings. The consumption pattern also depends on the type of guests. A hotel targeting business travellers has a pronounced peak, whereas tourist focused hotels have smoother consumption patterns spread across a longer period of time. Moreover, the demand is also depicted by the amount of water-intensive facilities the hotel offers. Consumption can vary greatly according to season and should be monitored to design the most optimal thermal system. The water consumption can be simply measured with a flow meter or water meter, resulting in the needed data to design the solar thermal system accurately.

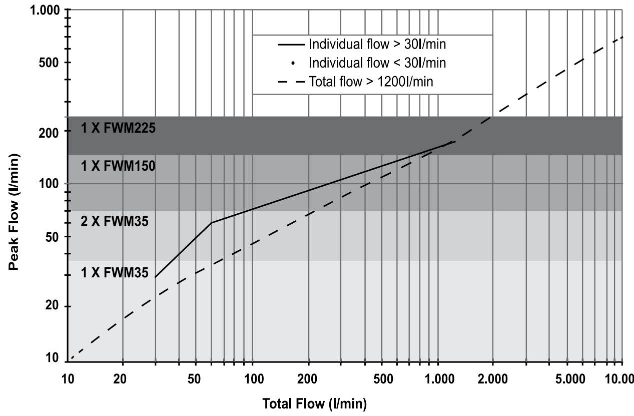


Figure 71: Peak flow for hotels

SELECTING A FLOW METER

For accurate measurements, the flow meter has to be carefully chosen. The meter must record very small amounts as well as very high flow rates during peak times. Important in the selection of the flow meter is the nominal flow rate V_n, which resembles the permissible continuous load of the flow meter. Additionally, also the maximum and minimum flows are crucial when deciding for a flow meter. The indicator V_{max} specifies the maximum water flow without damaging the meter, whereas V_{min} depicts the minimum amount of water the meter can detect reliably. The maximum expected peak flow is determined according to DIN 1988th (figure 71). Generally, it is sufficient to consider the total flow VR from all taps, as displayed on the x-axis. Following the curve in the diagram, the peak flow is presented by the y-axis.

MEASUREMENT PERIOD

The energy consumption has to be recorded over a period of time, preferably throughout all seasons to verify the peak demand of the hotel. The peak demand is usually during the summer months or at seasons in which the hotel reaches its highest occupancy rates. Ideally, the longer the measurement period, the more accurate is the data available to optimize the system design. However, a minimum time frame of at least 4-6 weeks can be sufficient.

TIME DATA READOUT

The data readout is the data of the water consumption. It is best to retrieve the data daily during the late mornings or afternoons with a simple counting mechanism or heat meter. Only in case of a logger, a device that stores the data, it is not necessary to retrieve the information on a daily basis. It is important to always retrieve the data at the same time of the day in order to gather comparable datasets.

RESOLUTION MEASUREMENT DATA

To design a collector system, daily consumption values on a five-minute or hourly interval are necessary. However, the higher the time interval, the less accurate is the design for the standby cylinder. If no current values are available, weekly or monthly values are sufficient to represent a suitable basis to determine the demand.

INSTALLING THE MEASURING DEVICE

Before installing the flow meter, it should be clarified which consumers are connected to the central hot water supply, in order to note explicit consumptions for each consumer (e.g. per room) later on. When entering the hot water consumption, the position of the flow meter is essential. The correct measurement position is directly after the cold-water inlet of the domestic hot water boiler, without any additional appliances in between. It is important to ensure that the flow meter is not installed on the boiler, which is discharging hot water, as then the total amount of water is counted circulating the system, rather than the hot water consumption.

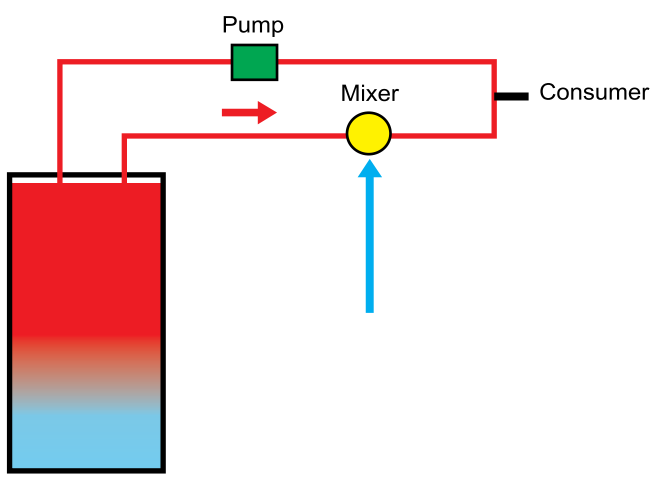


Figure 72: Circulation line from the boiler to the tap and back

CIRCULATION LINE

Hotels usually have a hot water circulation pipe to secure instant hot water supply. The circulation pipe needs a central hot water system that provides hot water even when the distance between the hot water generator and the outlet (tap, shower etc.) is long.

The circulation of a solar thermal assisted hot water system is usually covered by the conventional reheating system. Therefore, any heat losses due to circulation are irrelevant for the dimensioning of the collector field. If the solar-thermal system should cover the circulation heat losses, it is essential to know the length, diameter and thickness of its insulation. The heat demand of the circulation line can be as high as the hot water demand itself, if no proper isolation is installed. Further information on hot water provision in hotels is given in chapter 4, section 3.

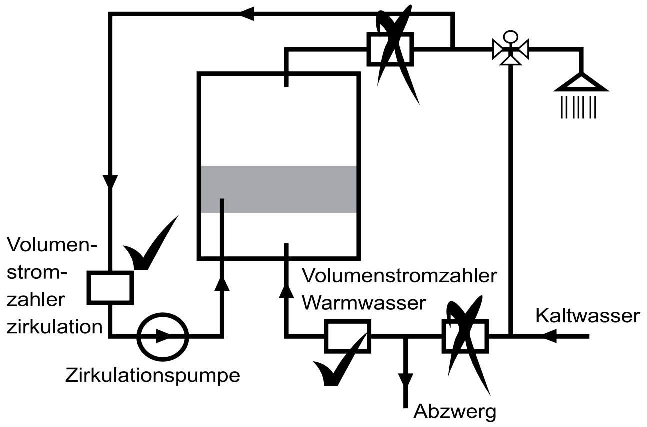


Figure 73: Position of the flow meter for measuring DHW water

DOMESTIC HOT WATER SYSTEMS

Existing hot water systems are often very complex. If the hotel facilities will be extended, the supply system must grow proportionally, resulting in an overwhelming network of hydraulic systems. Therefore, it is crucial for the hot water storage to be distributed evenly across the hotel resort, with the individual storage tanks aiming an equal load. Moreover, hygiene standards of the water storage tanks have to be met, especially when temperature levels drop below 40°C. At low temperatures the risk of dangerous bacteria (e.g. legionella) spreading inside the storage tanks is much higher.

WATER HYGIENE

For hotels it is of outmost importance to supply the guests with hygienically clean drinking water. The hygiene standards are set and regulated by the drinking water directive in each country. The risk of infection is regardless of the type of hot water system, whether it is a conventional or a solar thermal operated one.
Natural water purification cannot eliminate all types of bacteria, including Legionella. Under a certain amount of time and temperature conditions, various types of bacteria can enter the drinking water supply system of any hotel, which has hazardous consequences for the consumer. Especially in temperatures between 30°C and 45°C is the risk of bacteria spreading and growth the highest. Additionally, stagnant waters, encrusted surfaces and an insufficient water flow through the pipelines can facilitate water contamination. To ensure bacteria free water, temperatures of above 50°C are required. As a general rule, the higher the temperature, the shorter the time frame to eliminate any bacteria in the pipelines and storage tanks.


Figure 74: Complex hydraulic domestic hot water system in a touristy hotel

MEASURES FOR WATER HYGIENE

According to the German drinking water regulations, water hygiene measures depend on the scale of the water plants. For small hot water tanks up to 400 litres, with a hot water content of the associated pipeline network of less or equal to 3 litres, only limited requirements to reduce the risk of infections apply. Anything above 400 litres is regarded as a large-scale water plant. In large-scale plants, the water outlet of the drinking water heater has to have a minimum temperature of 60°C. In addition, it must be ensured that the water in the pipeline is evenly heated. Systems designed to provide immediate access to hot water require a hot water tank that is constantly set at 60°C and reheats whenever the temperature drops below 60°C. For large systems with floor cables whose pipeline capacity is greater than 3 litres, the worksheet demands circulation operation as mandatory. The circulation lines should be large enough for the circulating water to cool by more than 5K* compared to the outlet temperature at the hot water tank. In addition, the water flow should not be interrupted for more than 8 hours a day.

DIGRESSION: LEGIONELLA

Legionella is rod-shaped bacteria that exist in fresh water at a very low concentration. In stagnant warm water, legionella rapidly multiplies and can cause hazardous health issues (> 102-103 legionella per ml). An infection occurs through inhalation of contaminated aerosols, for instance through air-conditioning systems or in the shower. The legion ropes settle in the lungs where they penetrate the alveoli. In severe cases a Legionella infection can cause pneumonia.

ENVIRONMENTAL CONDITIONS: SEAWATER AND SEA AIR

Depending on the location and climatic conditions, solar thermal collectors have to bear high climatic and mechanical stress. The degradation of the system is increased, through high temperatures, UV-light, wind, snow, humidity or saline and corrosive atmospheres. To minimize corrosion of the collectors and pipework, the solar thermal system should be installed at least 200 meters away from the seashore.

SPECIFICATIONS FOR WATER AS A HEAT TRANSFER

MEDIUM

Antifreeze is often used as a heat transport medium in collector systems, but it is also possible to use water instead. In case water is used, the operator must adhere strictly to the collector specifications of the manufacturer. One of the specifications is the chloride and sulphate content in the water, which must not surpass a certain level to avoid corrosion.

ADVANTAGES FOR USING WATER INSTEAD OF ANTIFREEZE:

- Slightly higher heat capacity
- Cheaper
- Available everywhere
- No stagnation problems

IMPORTANT: Antifreeze can demolish the Collector at high temperature levels. The antifreeze must be suitable to the type of collector, especially when a vacuum tube collector is used (> 250°C).

ROOFTOP

In many cases, the roof of a hotel is constructed as a flat roof. In this case, solar collectors compete with air-conditioning on space. Both air-conditioning and solar thermal systems need to be installed on the roof. It is best for solar thermal systems to be fixed in a continuous straight line across the roof in order to lower the costs of installation. A possible solution is to move the air-conditioning cooler onto the edges of the roof or between two complete collector lines to generate space for the thermal system without reducing the number of air conditions (figure 76).

* K = Kelvin

SOLAR COLLECTOR SYSTEMS FOR DOMESTIC HOT WATER AND POOL HEATING

Figure 75: corrosion on pipework through the aggressive water from the sea

When installing a solar thermal system, it is beneficial to not only install the system for the hot water demand of the hotel only, but also integrate the thermal system for pool heating. A solar thermal system transfers heat whenever there is a heat demand. Yet, the energy demand for pool heating during summer is quite low in the MENA-region. The pools are mainly heated by sunshine without the use of any additional heating systems. Therefore, it is essential to size the solar system to the needs of the hotel according to its minimum demand to avoid oversizing the system.

THE ENERGY DEMAND OF A POOL DEPENDS ON SEVERAL FACTORS:

- Shape of the pool
- Dimension of the pool
- Covered or open-air pool
- Windshield (none, partial, full)
- Shade (low or high)
- Desired temperature

Figure 76: Typical space situation on flat roofs for hotels

The possible solar fraction for a solar thermal system is limited, if only the minimum demand is covered. To increase the solar fraction, the thermal system has to be oversized, resulting in excess solar energy at the summer months with the most sunshine irradiation. A simple solution is to use a pool as a hot water buffer. The system would overheat the pool up to 30-32°C as a hot water buffer tank. By doing so, the system runs smoothly during the day without facing any stagnation of the collector field, as any excess can be transferred into the pool.

There are extremely high heat losses during night time. These losses can only be stored via existing boilers or a solar system in case a large solar buffer tank has been installed to store the energy generated during the day. This leads to a high buffer volume and additional costs for the solar system.

EXAMPLE 5

Volume buffer

1m² of a solar thermal system gains about
Q = 4 kWh/day
$Q = m \times c \times dT$
Q = energy in kWh
m = volume m³
c = heat capacity of water (constant 1.16kWh/m³K)
dT = max. delta of the temperature in the buffer tank (here max. 90°C , min. 35°C = 55 °C (K) dT)
m = 4 kWh/(1.16 kWh/m³K × 55K) = 63l

As a result: To store solar energy from daytime for the use during night time, each installed m³ needs at least 63l buffer volume.

EXAMPLE 6

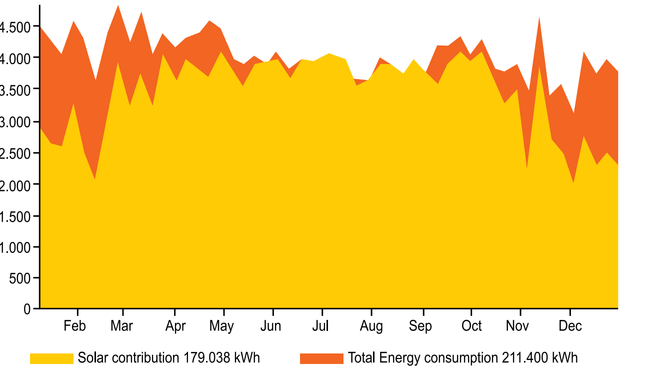
Energy demand

In this example the energy demand of a typical hotel (domestic hot water + pool heating) and the solar thermal system are designed without any oversizing of the solar system.

Main consumption data of the hotel:
7000 l/d domestic hot water consumption
Circulation line 150m (well insulated)
Operating time: 20h/day
Pool surface: 600 m²

- Without cover
- No windshield
- Low shade
- Desired temperature 24°C
- Max. swimming pool temperature at 32°C

The maximum collector temperature over the year is a perfect indicator of a well-designed solar system. When the collector field is optimally sized and designed according to the hotel's demand, the temperature of the collector remains low. In case of a stagnating system, the temperature of the collectors can rise up to 180°C. Regardless of the ambient temperature, such high temperature levels should not be reached.



(75% of DHW and 40 % of the operating hours pool temperature above desired level of 24°C) of a solar system installation of 153 m² on the roof.

Figure 77: Total energy consumption of a typical hotel for DHW and swimming pool with a very high solar fraction

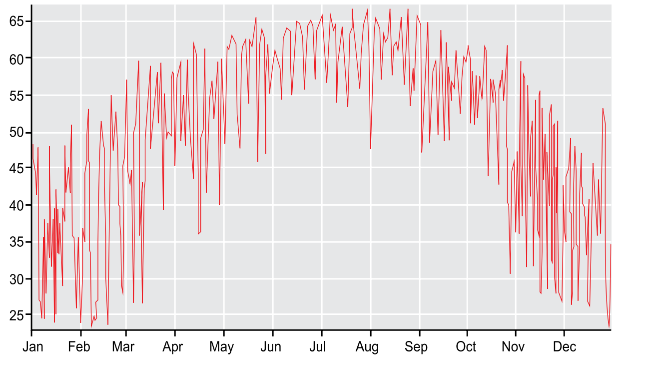


Figure 78: Maximum yearly collector temperature of a well-designed collector field with very low collector temperature.

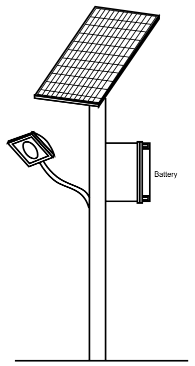
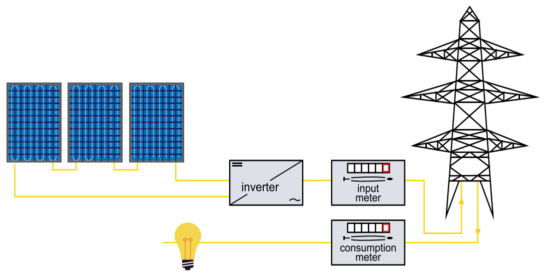
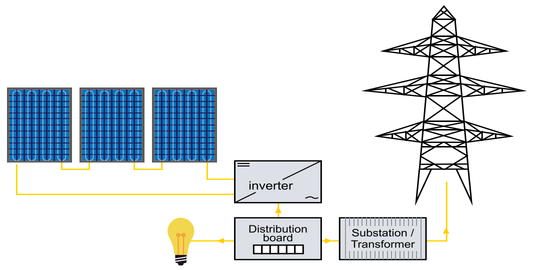
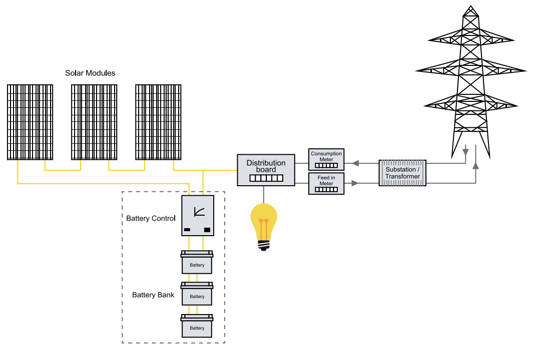
SYSTEM TECHNOLOGIES FOR POWER & HEAT

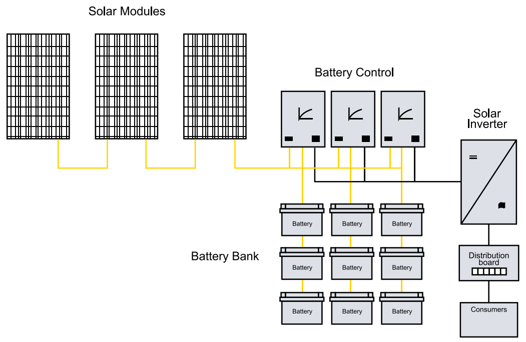
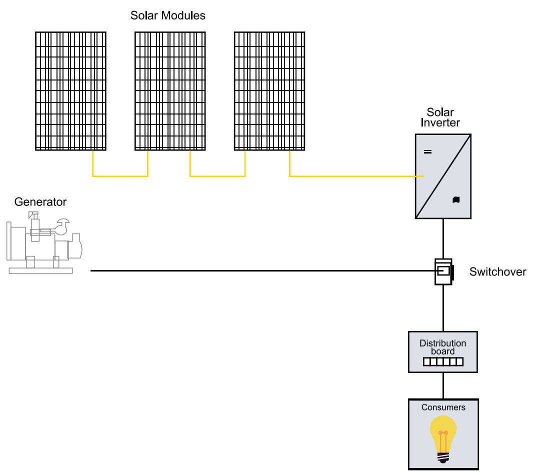
Chapter Two

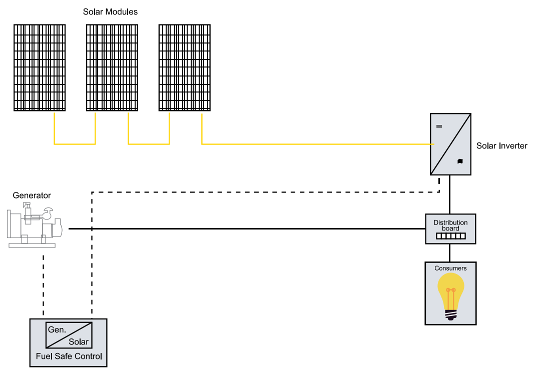
02

2.1.1 SYSTEM OVERVIEW SOLAR POWER SYSTEMS

The following table gives an overview of several solar power system types. A short description of the application and some advantages/disadvantages are explained.

System	Application	Advantages/ Disadvantages
Small independent units Complete standardized units applicable for any electrical outlet (e.g. LED light) in combination with a PV module, a battery and an internal control system. 	• Outdoor lighting • Gardening • Fountains	**Advantages:** • Easy to install • Simple Sizing • Cost efficient **Disadvantages**: • Higher initial investment
Grid-connected feed-in systems The system is connected to a substation of the public grid and is compensated for each kW fed into the public grid under the country-specific feed-in tariff (only applicable for countries with feed-in tariff policies). Generated solar power is supplied to an external grid, with power demand sourced the same way as from the utility. 	• Any hotel with a connection to the public grid • Possible feed-in tariff solution	**Advantages:** • Very simple sizing • Cost effective • Investment opportunity **Disadvantages:** • Lengthy • application process • Depends on public policy
Self-consumption systems The solar power system is connected to the main distribution board of the internal grid. All generated solar power is used internally and reduces the need for electricity from the public grid. To increase the reliability of the self-consumption system, batteries can be added and loaded during daytime and used whenever fluctuations in solar irradiation occur. Adding batteries lessens the need for electricity from the public grid. Self-consumption systems with batteries can be designed as a back-up system to overcome possible power cuts. However, the back-up systems have only a limited function as the capacity of the batteries is aimed to only cover the time of a power cut and not for sole reliabilty for energy supply during night time, when no solar power is generated. 	• Any hotel with a connection to the public grid • Possible feed-in tariff solution	**Advantages:** • Cost savings • Independence from public grid • Stable power generation costs **Disadvantages:** • Not as predictable as feed-in systems • More complex sizing • Limited solar fraction when no batteries are used
Net-metering systems The solar power system is connected to the main distribution board of the internal grid. The generated solar power is used primarily, which lowers the amount of electricity purchased from the public grid. Any solar power in excess can be supplied to the utility at a fixed rate, in case of a feed-in tariff scheme in place. Batteries can be added to prolong the depedence on the self-consumption system. 	• Any hotel with a connection to the public grid • Possible feed-in tariff solution	Advantages: • Simple sizing • No batteries required (but optional) • Cost efficient Disadvantages: • Energy compensation through feed-in tariff depends on country-specific policies

Stand-alone solar systems with batteries The stand-alone system relies solely on solar power and batteries. Its system size is designed to cover the energy demand during the day as well as to charge the batteries to cover the power demand during night time. Solar power supplies electricity during sunshine hours and charges the batteries to supply electicity at night time or at times with insufficient solar irradiation 	• Off-grid locations with difficult access to additional fuel sources (e.g. mountain huts, islands, coastal resorts) • Applications, which require silent and emission-free power generation	**Advantages:** • Independent electricity supply • Silent and emission free **Disadvantages:** • Complex sizing • High capital investment
Hybrid systems with switch operation The solar power system is combined with a standard diesel generator. Whenever solar irradiation is sufficienctly high to serve the energy demand, the system solely relies on solar power. At night time or during insufficient solar irradiation, the system switches from solar power to the diesel generator, which cover 100% of the energy demand. Batteries can be used to prolong the solar operating time. 	• Off grid locations with acceptable access to additional fuel sources	**Advantages:** • Easy operations • Existing generators can be used **Disadvantages**: • Oversizing of solar power system required • Daily peaks of solar power generation is lost if no batteries are used • Limited solar fraction without batteries

Fuel saver solution The solar power system is combined with a flexible diesel generator. The solar power system and the generator operate in synergy and are controlled by one management system to secure the energy output. The controller of the management system ensures that the system is always operating on the highest performance and most cost-efficient level. The generator can operate at all times, yet on a minimum load to save fuel and support the solar power system to satisfy the energy demand. Batteries can be used to optimize the system operations by increasing the use of solar power and decreasing the fuel need for the generator. 	• Off grid locations with acceptable access to additional fuel sources	**Advantages:** • Higher efficiency compared to switch operation system • Simpler sizing • No oversizing of the solar power system needed **Disadvantages:** • Flexible generators required • Higher investment needed for management system

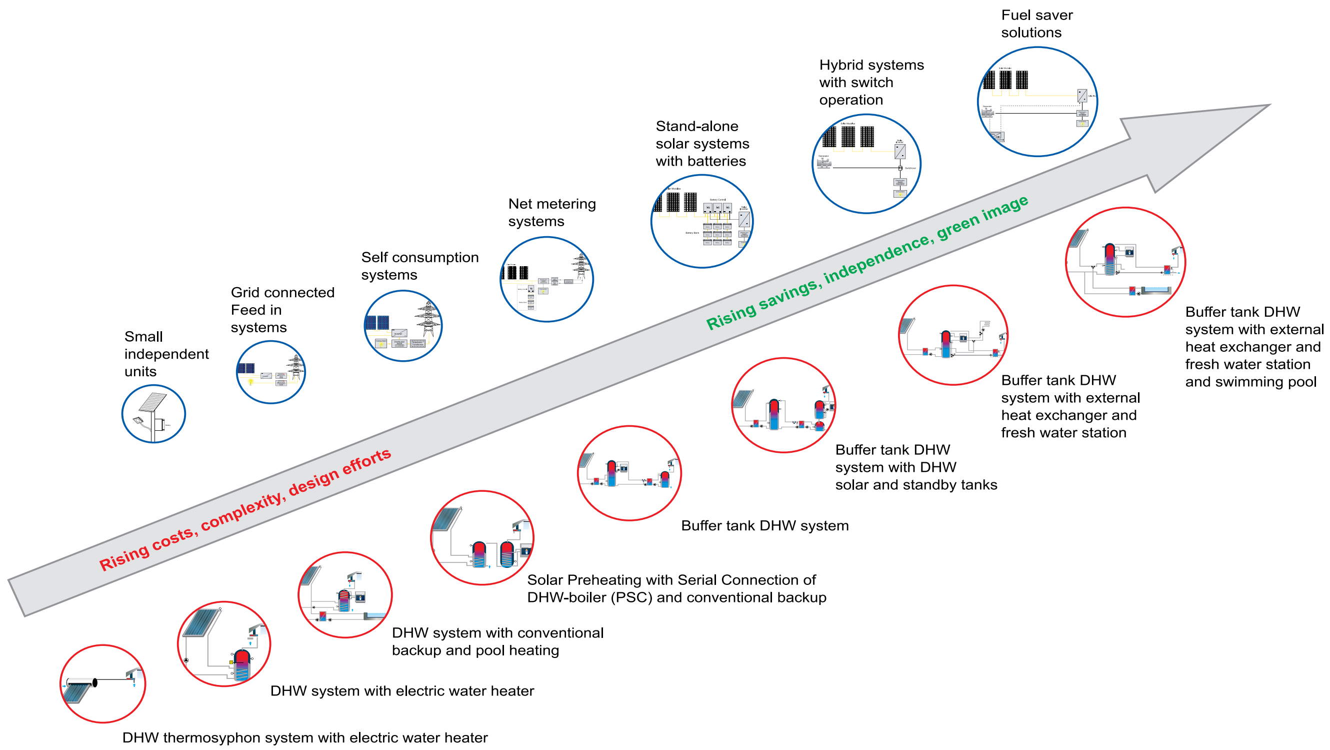


Figure 79: Solar Power Solutions

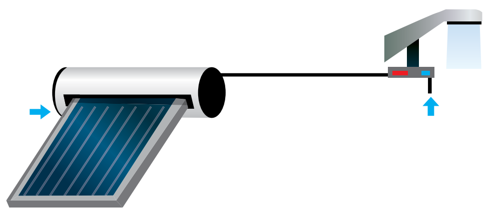
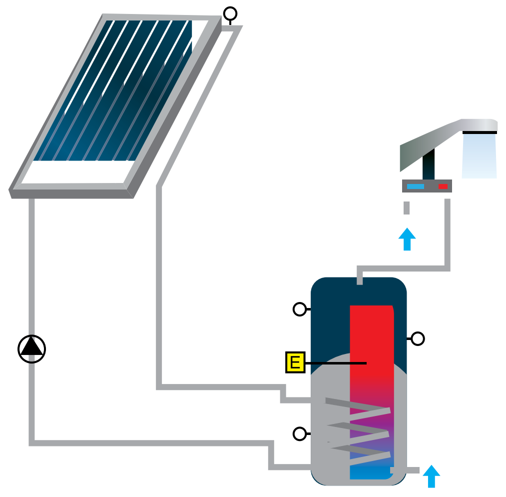
2.1.2 SYSTEM OVERVIEW SOLAR THERMAL SYSTEMS

FACTORS INFLUENCING A SOLAR THERMAL SYSTEM:

- Heat demand
- Size of the collector field
- Type of application (domestic hot water and/or pool heating)
- Back-up heating system (gas, oil, electricity etc.)
- Dimensions of the boiler room

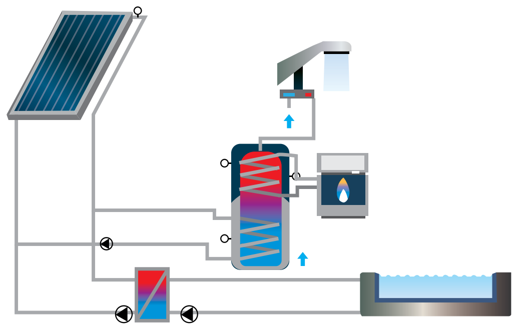
The following table gives an overview of several solar thermal system types.

A short description of the application and some advantages/disadvantages are explained.

System / Description	Application	Advantages/ Disadvantages
A domestic hot water (DHW) thermosyphon system with an electric water heater The system operates automatically when the sun heats up the collector. It does not require any pumps as it is only based on the thermosiphon effect. It can be built as either a one- or two-loop system. In a one-loop system the DHW runs through the collector into the tank, in which it is directly available to the end consumer (e.g. shower). It is a very effective and economic system, however since the heated water is directly transferred to the end consumer, the one-loop system is not the most hygienic solution. In a two-loop system the solar application and the tank are separated. The first loop only fills the DHW tank, whereas the second loop connects the tank to the collector. In both systems the water temperature is defined by the sun irradiation only, as no control system is included in the design. 	• Only DHW • Capacity for one family house • Max. size approx. 4m² with a 300l tank. • Can be connected to several systems to increase the output of the DHW	**Advantages:** • Economic • Simple installation • No pump needed **Disadvantages:** • Only for DHW • Only for smaller applications with a maximum demand of 300l/d. • Only suitable for an electrical back-up
A DHW system with an electric water heater This system uses a pump as a controller to transfer the heated water when needed. Whenever the collector is on a higher temperature level than the tank, the system will start to load the boiler through a heat exchanger (coil) in the DHW tank. The tank is the interface of the system connecting the water circulating in the collector field to the end consumer. A pump circulates the water, whenever the collector temperature is higher than the temperature of the water tank. In case of insufficient solar irradiation either electronic immersion heaters or heat exchangers are used to regulate the temperature of the water used for the end consumer, e.g. the shower. 	• Only DHW • Capacity for one family house up to smaller hotels • Max. size of the tank approx. 3000l tank • For larger application the tanks can be connected in serial to bring out a higher output.	**Advantages:** • Robust system • Easy operation **Disadvantages:** • Only for DHW • Less hygienic (risk of legionella) • Hygiene risks can increase when system is enlarged by connecting several tanks • Only suitable for an electrical back-up

A DHW system with a conventional back-up system and pool heating

Similar to the previous system, the pump acts as a controller to regulate the temperature between the tank and the collector field by transferring water whenever the temperature in the collector field exceeds the temperature in the tank. When the collector is on a higher temperature level than the tank, the system will start to load the boiler through a heat exchanger (coil) in the DHW tank.
The difference between the two solutions is that a pool is used as an enormous back-up system, which allows the solar thermal system to be oversized. Thus, it is able to meet higher demand periods, than a system without a back-up option. The system operates via a changeover valve in the solar application, which allows excess DHW to be transferred into the pool, whenever the tank is filled. The primary goal is to fill the DHW tank, and the pool is only used in case of excess solar energy, thus excess DHW.



- Suitable for DHW and pool heating
- Capacity for one family house up to smaller hotels
- Max. size of the tank approx. 3000l tank
- Can be connected to several systems to increase the output of the DHW

Advantages:

- Robust system
- Easy operations
- For DHW and pool heating
- All kinds of backup heating possible

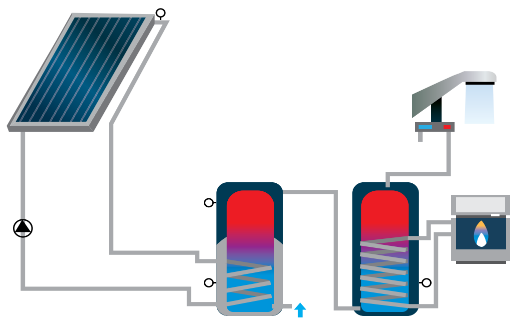
Disadvantages:

- Less hygienic (risk of legionella)
- Hygiene risks can increase when system is enlarged by connecting several tanks

A solar pre-heating system with a serial connection between the DHW-boiler

A solar energy system preheats the water first (left tank) and is then connected to the back-up tanks (right tank), which can be several tanks connected to one another.

This type of solar and thermal combination is one of the most common hotel applications.
A detailed description is given in chapter 2, section 2.



- Suitable for DHW and pool heating
- Capacity for one family house up to smaller hotels
- Max. size of the tank approx. 3000l tank.
- Possible to enlarge the

Systems to several solar preheat and back-up tanks connected in parallel to increase DHW output

Advantages:

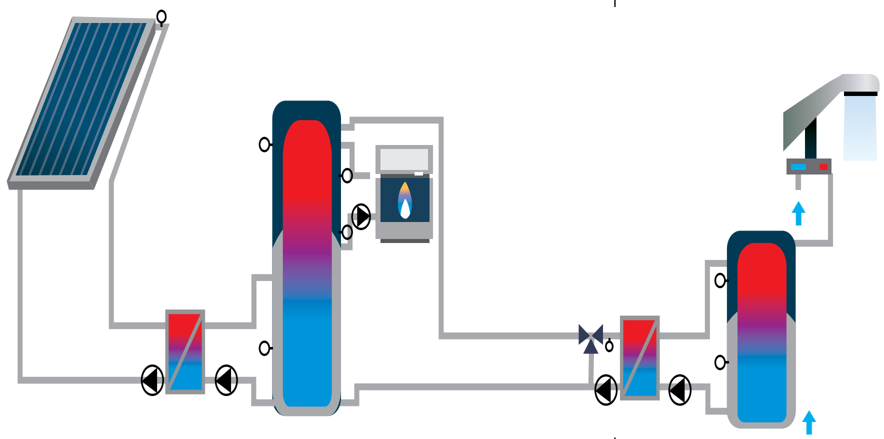
- Robust system
- Easy operations
- Suitable for DHW and pool heating
- All kinds of back-up heating possible

Disadvantages:

- Less hygienic (risk of legionella)
- Hygiene risks can increase when system is enlarged by connecting several tanks

A DHW system with a buffer tank

Instead of using preheat enabled boilers, this system makes use of a buffer tank (left tank). The solar load is transferred via an external heat exchanger to a primary (left) and secondary (right) pump. For smaller systems internal heat exchangers are sufficient. Back-up heating in the buffer tank is always set on 70°C to sustain a constant temperature level of 60°C for the DHW. The water in the DHW tank is loaded with a primary (left) and secondary (right) pump as well as an external heat exchanger (right tank).



- Suitable for DHW and pool heating
- Flexible capacity for any type of hotel
- Buffer tanks are available in size up to 100m³ in per tank

Advantages:

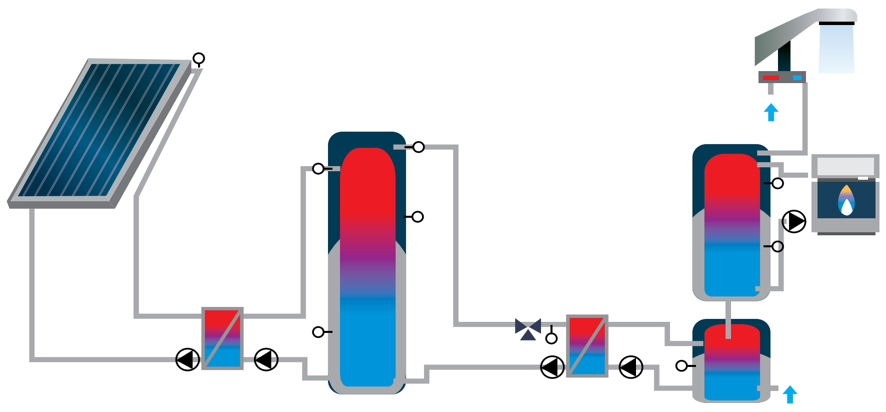
- Robust system
- Suitable for DHW and pool heating
- All kinds of back-up heating possible
- Perfect heat transfer for large collector fields
- High hygiene standards
- Less prone to bacterial infections (e.g. legionella) in the DHW tank
- Lower investment costs for large scale systems

Disadvantage:

- Needs a larger controller
- Higher investment costs for small scale systems

A DHW system with a buffer and standby tanks

Similar to the previous system, no preheat compatible boilers are used, but instead a buffer tank is installed (left tank). The solar
load is transferred via an external heat exchanger to a primary (left) and secondary (right) pump. For smaller systems internal heat exchangers are sufficient. The DHW tanks (right tanks) are separated from the preheat tank (tank below) and the standby tank (upper tank).
The water load of the preheat tank is transferred to the buffer tank via an external heat exchanger and two pumps, a primary (left) and a secondary (right) pump, whereas the back-up DHW load is heated in the standby tank.
This solution is one of the most applicable systems for hotel applications.
For a detailed description, refer to chapter 2, section 2.



- Suitable for DHW and pool
- Flexible capacity for any type of hotel
- Buffer tanks available in sizes up to 100m³ per tank

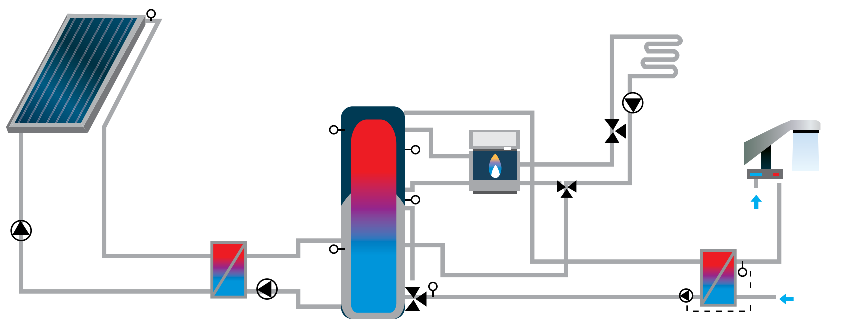
Advantages:

- Robust system
- Suitable for DHW and pool heating
- All kinds of backup heating possible
- Perfect heat transfer for large collector fields
- High hygiene standards
- Less prone to bacterial infections (e.g. legionella) in the DHW tank
- Lower investment costs for large scale systems
- Can be well integrated into existing DHW tanks via the installation of a preheat solar system
- Well suitable for very high peak demands

Disadvantages:

- Needs a larger controller
- Higher investment costs for small scale systems

A **DHW system with a buffer tank, an external heat exchanger and a fresh water station** Also for this system, no preheat boilers are needed, but instead a buffer tank (left tank) is installed. The solar load is transferred via an external heat exchanger to a primary (left) and secondary (right) pump. For smaller systems internal heat exchangers are sufficient. For the backup heating, the buffer tank is set on 70°C to sustain 60°C in the DHW tank. The direct flow from the buffer tank into the DHW tank is via a heat exchanger. Thus, whenever the DHW tank is tapped, a pump starts to transfer the heat to the fresh water station (heat exchanger on the right site). Space heating is also an option through under floor heating. This solution is one of the most applicable systems for hotel applications. For a detailed description, refer to chapter 3, section 2.	• For DHW and pool heating • Flexible capacity for any type of hotel • Buffer tanks available in sizes up to 100m³ per tank • Fresh water tanks	**Advantages:** • Robust system • Suitable for DHW and pool heating • All kinds of backup heating possible. • Perfect heat transfer for large collector fields • High hygiene standards • Less prone to bacteria infections (e.g. legionella) in the DHW tank • Lower investment costs for large scale systems • Can be well integrated into existing DHW tanks via the installation of a preheat solar system **Disadvantages:** • Higher investment costs for the fresh water station needed at peak demand • Needs larger controller • Higher investment costs for small scale systems



A DHW system with a buffer tank, an external heat exchanger, a fresh water station and a swimming pool This is the same technology as the previous system. The only difference is the addition of a swimming pool as a buffer tank.	• Alternative with pool heating • Internal charge for the buffer tank of smaller solar systems of need a collector field of approx. 25m²	• See previous system

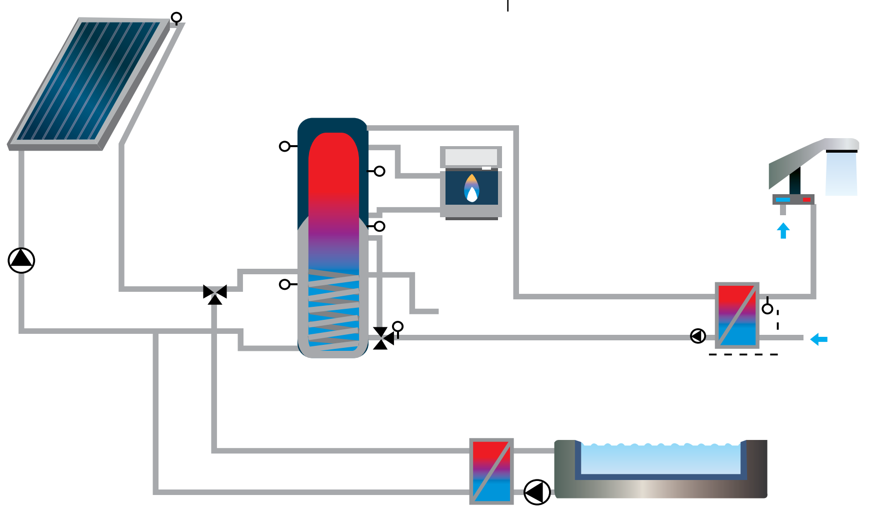


Figure 80: Solar power installations

2.2 SYSTEM SOLUTIONS FOR SOLAR POWER AND HEAT

2.2.1. SYSTEM SOLUTIONS FOR SOLAR POWER

Solar power (i.e. PV system) generates electricity by converting solar irradiance into DC power via PV modules. The modules are usually installed either on rooftops or as a ground installation for larger systems, however special structures, such as carports or greenhouses are also possible. In smaller independent units, DC power is used directly. However, for most applications it has to be converted into AC power. The conversion is done via inverters that are connected to the consumer board or the public grid. A monitoring and control unit observe the operation.

If batteries or other power generating facilities (e.g. generators) are included in the concept, an adequate control system must be included to charge the batteries, manage the generators as well as consumers. In fact, in any solution, batteries can be added to balance short-term fluctuations or to prolong solar operation.

Types of solar power systems for hotels

- Small independent units (e.g. street lights, gardening pumps, etc.)
- Feed-in systems
- Support systems for self-consumption
- Systems with or without batteries
- Stand-alone off-grid systems

2.2.2 SMALL INDEPENDENT UNITS

Solar streetlights combined with efficient LED technology to light trails and streets without any wiring are already very popular in the public and commercial sector.

Solar streetlights are comparable to solar water pumps that have a relatively small solar panel in a range up to several hundred Watt, which is connected to a charge control and a battery to run the device during non-sunshine hours (evening and night time). The consumer is using DC power of the panels and is directly connected to the battery without the use of inverters.

Applications for small independent units are:

- Streetlights
- Landscape lighting
- Watering and irrigation of small areas without critical crops
- Fountains and water games
- Wifi-hotspots
- Security cameras

Figure 81: solar streetlight and fountain pump

Small independent solar systems are economic, when wiring or internal grid-connections can be avoided. Maintenance of such solutions is limited and mainly consists of cleaning the panels and replacing the batteries. Independent units are well established in the market and are high quality and long lifetime. However, as for any solar application, the lifetime of an independent solar system depends on the quality of the components purchased.

EXAMPLE 7

Solar streetlights
Advantage:

- Very simple sizing
- Cost-efficient
- Attractive investment
- Safe costs on wiring
- No supplementary energy required

Disadvantage:

- Higher initial investment compared to on-grid solutions

Necessary to check for design:

- Check unit quantity and performance on required flow rates and light intensity

Necessary components:

- Standardized units with PV-panels
- Charge control
- Batteries

2.2.3 GRID CONNECTED FEED IN SYSTEMS

Grid connected feed-in systems are the simplest systems to realize. However, they are only possible in countries with feed-in tariff or net-metering policies, which allow transferring solar energy into the public grid for a profit or credit.

The sizing of the system is independent from the demand profile and only depends on the budget and available space on the roof. Before installing a grid-connected solar system, it has to be verified whether there are any limitations regarding the size of the system according to local policies and regulations. Further, maximum capacity restrictions of the public grid substation have to be verified to which the solar system will be connected.

Once the solar system is installed, its sole purpose it to supply the generated solar energy into the public grid. For any kWh supplied, the system owner receives a compensation based on the country-specific feed-in tariff (FIT). The own energy consumption is still retrieved from the public grid.

In order to be compensated for the solar energy transferred to the public grid, two meters have to be integrated, (1) a power meter to count how much energy has been fed-in to the grid and (2) a meter that measures how much energy has been purchased. In most cases, the rates for feed-in and power purchase differ. Thus, its economic feasibility of the investments is depicted by the feed-in tariff rate, the achieved solar yield and the lifetime of the system as such.

In some countries, local regulations request special control and safety measures, such as external access to the power management of the solar power system, in case of any grid disturbances (i.e. grid and system protection). Further, they might require the system to have an additional state-owned meter to accurately monitor the energy supplied to the grid.

The application and approval process also depend on the local policies and regulations. Some countries require the operator to apply for a power generation license and power purchase agreements from the utility. Thus, local policies and regulations have to be checked and adhered before installation.

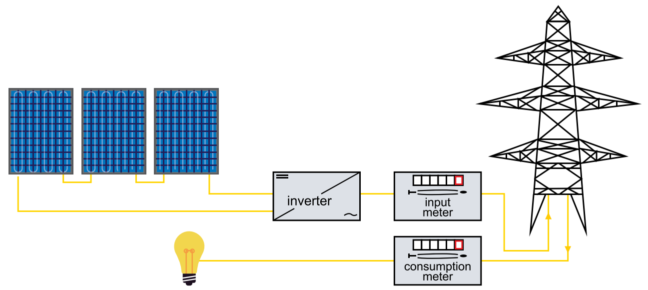


Figure 82: Feed-in tariff system

When calculating the maximum possible solar energy output, the degradation (i.e. performance losses due to aging) of the system has to be included. The rate of degradation can be found in the datasheet of the components. Based on realized feed-in tariff projects in Europe, solar energy compensation can be expected to be at least 20 years. In case of a limited feed-in tariff of less than the system's lifetime, the solar application can always be switched to a self-consumption facility to provide energy for own usage.

EXAMPLE 8

Feed-in tariff system
System: 150 kWp

Location: Hurghada, Egypt

Feed in Tariff: 0.918 LE/kWh (0.093 €/kWh – June 2016)

Solar power generation: 2,075 kWh/year

Degradation: 20% in 25 years of operation = 0.8% per year

Investment: 225,000€

Advantage:

- Very simple sizing
- No detailed demand profile needed
- Cost-efficient
- Attractive investment (net profit after pay-back time)
- Easily upgradable to a back-up system or a system with batteries

Disadvantage:

- Savings depend on feed-in tariff
- Stable feed-in tariff reduces lucrativeness of investment
- Sometimes lengthy applications and approval processes
- Information needed prior installation:
- Grid connection capacity for feed-in systems
- Local policies and regulations
- Roof area and structure (remaining lifting capacity)
- Shading effects
- Necessary components:
- PV area with support structure
- Inverters
- AC connection units
- Metering for feed-in power

2.2.4 SELF CONSUMPTION SYSTEM COUPLED WITH A FEED-IN TARIFF AGREEMENT

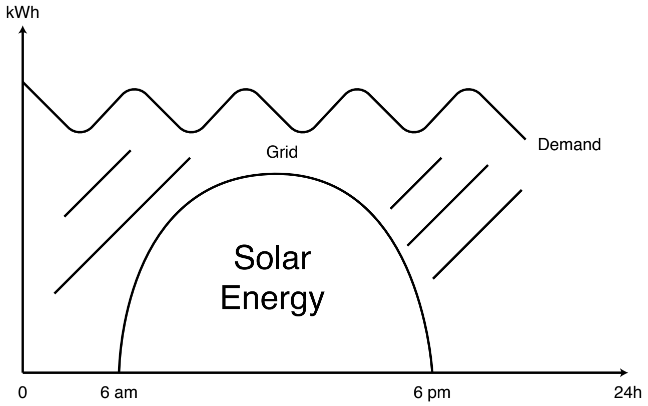


Figure 83: Load profile without batteries (solar output < load profile)

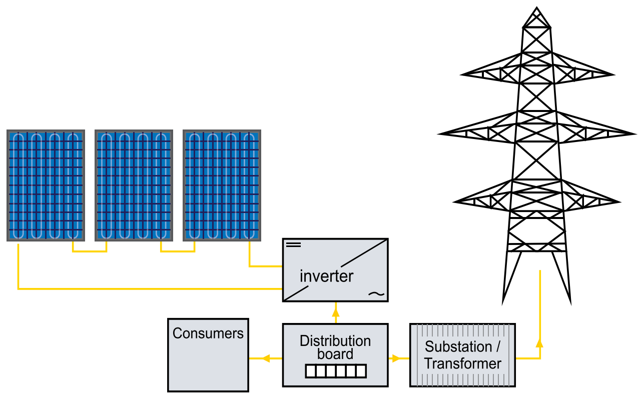


Figure 84: Self-consumption system without batteries

In a solar system for self-consumption, energy is supplied by the solar system according to the demand profile. Any solar energy excess is transferred to the public grid in return for a feed-in tariff or net-metering, given policies are in place. In case of no feed-in tariff scheme, a control system in the solar application reduces the solar output to match the demand profile. When the demand profile exceeds the solar output, the public grid supplies the energy gap under the same principle as any other conventional energy system. The aim of a self-consumption system is to reduce own energy costs through the use of solar energy. Energy costs are further reduced if the solar system is coupled with a feed-in tariff agreement, as for any kWh fed into the grid a set compensation is received.

Project: Sample feed in system **Location:** Hurghada, Egypt

System type: Self-Consumption **degradation** 0,80 % p.a.

System Power 150 kW **specific solar yield:** 2075 kWh/kWp p.a. **operational costs:** 0,2 % of invest

Feed in tariff: 0,09 EUR/kWh **increase of feed in tariff:** 0% p.a. **investment:** 225.000,00 €

year of operation	1	2	3	4	5	6	7	8	9	10
solar yield kWh/a	311.250	308.760	306.290	303.840	301.409	298.998	296.606	294.233	291.879	289.544
accumulated solar energy kWh	311.250	620.010	926.300	1.230.140	1.531.548	1.830.546	2.127.152	2.421.384	2.713.263	3.002.807
energy price in EUR/kWh	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09
fed in compenstaion in EUR	28.013	27.788	27.566	27.346	27.127	26.910	26.695	26.481	26.269	26.059
operational costs in EUR	450	450	450	450	450	450	450	450	450	450
accumulated earings in EUR	27.563	54.901	82.017	108.913	135.589	162.049	188.294	214.325	240.144	265.753
account balance in EUR	-197.438	-170.099	-142.983	-116.087	-89.411	-62.951	-36.706	-10.675	15.144	40.753

year of operation	11	12	13	14	15	16	17	18	19	20
solar yield kWh/a	287.228	284.930	282.650	280.389	278.146	275.921	273.713	271.524	269.352	267.197
accumulated solar energy kWh	3.290.035	3.574.965	3.857.615	4.138.004	4.416.150	4.692.071	4.965.784	5.237.308	5.506.659	5.773.856
energy price in EUR/kWh	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09
savings in EUR	25.850	25.644	25.439	25.235	25.033	24.833	24.634	24.437	24.242	24.048
operational costs in EUR	450	450	450	450	450	450	450	450	450	450
accumulated savings in EUR	291.153	316.347	341.335	366.120	390.703	415.536	440.171	464.608	488.849	512.897
account balance in EUR	66.153	91.347	116.335	141.120	165.703	190.536	215.171	239.608	263.849	287.897

year of operation	21	22	23	24	25
solar yield kWh/a	265.059	262.939	260.835	258.748	256.678
accumulated solar energy kWh	6.038.915	6.301.854	6.562.689	6.821.438	7.078.116
energy price in EUR/kWh	0,09	0,09	0,09	0,09	0,09
savings in EUR	23.855	23.664	23.475	23.287	23.101
operational costs in EUR	450	450	450	450	450
accumulated savings in EUR	536.752	560.417	583.892	607.179	630.280
account balance in EUR	311.752	335.417	358.892	382.179	405.280

a) Pure self-consumption systems

Pure self-consumption systems are used, if no local policies for net-metering or feed-in are available. For solar systems with a smaller solar output compared to the total energy load profile, no batteries are needed, since the system will not generate any excess energy. It is only connected to the main- or sub-distribution board at a suitable capacity, in which the solar power is used internally. Such solar applications do not require any control systems and are working fully automatically.

In some countries, local regulations require a control switch that reduces the solar output to match the demand or in case of zero demand, switches the solar system off, to avoid any solar energy excess to be fed into the grid. In such cases, the solar system is specifically designed to match the demand profile during daytime, to reduce the risk of wasting any generated solar power. Further, these systems are usually not designed to have a back-up system, and therefore need to be grid-connected in order for the system to sync to an existing grid (e.g. public grid or generators). Hence, other than the island solution, the self-consumption systems are not able to create their own grid in case of instable power supply (e.g. power cuts).

b) Self-consumption with batteries

There are several possibilities to increase the reliance on the solar self-consumption system. The inclusion of batteries into the design concept is one of the possibilities to prolong the use of solar energy or to smoothen operations in case of strongly fluctuating demand, especially in bigger sized systems. The batteries store any excess solar energy generated when demand is lower than the system design expectation or at times of above-average solar irradiation. The stored energy can be used to prolong the self-consumption or in case of bigger battery banks provide electricity at night time. The self-consumption increase depends on the battery size.

Thus, the solar system is not only designed based on the daily load profile, but includes the demand during night time. A solar self-consumption system with batteries is reasonable, when the demand during daytime is very volatile and the batteries can store energy over a short period only to balance fluctuations in the demand/supply profile.

Systems with batteries can be combined with a back-up function for limited capacity, in case the battery capacity is sufficiently high and the type of inverters allow building its own stable grid.

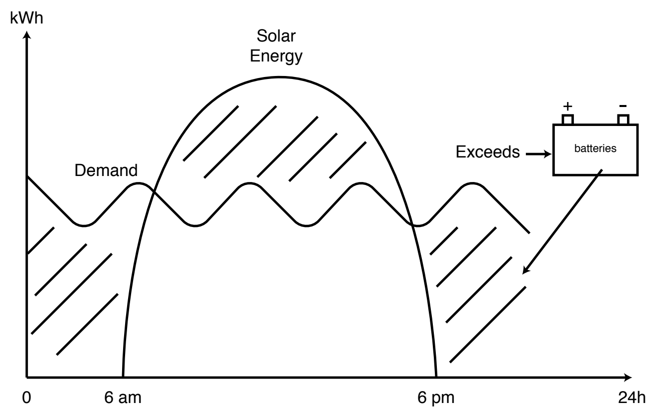


Figure 85: Load profile with batteries (solar output < load profile)

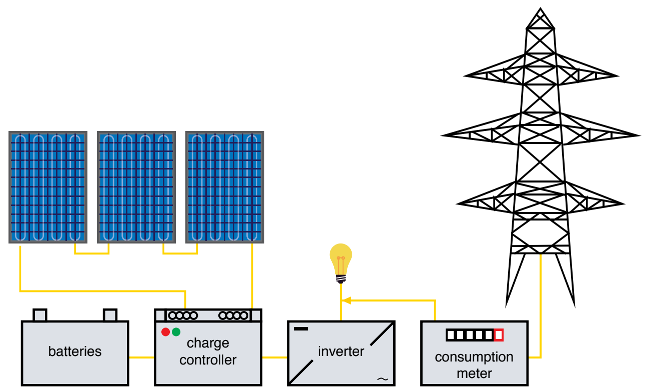


Figure 86: Self-consumption system with batteries

EXAMPLE 9

Self-consumption without batteries

System:	150 kWp without batteries
Location:	Hurghada, Egypt
Energy price:	0.7 LE/kWh (0.07 €/kWh – June 2016)
Energy price increase:	20% p.a.
Solar power generation:	2,075 kWh/year
Degradation:	20% in 25 years of operation equal to 0.8% p. year
Investment:	225,000€

Project:	Sample self-consupmtion	Location:	Hurghada, Egypt		
System type:	Self-Consumption	degradation	0,80 % p.a.		
System Power	150 kW	specific solar yield:	2075 kWh/kWp p.a.	operational costs:	0,2 % of invest
Energy Price:	0,07 EUR/kWh	increase of energy price:	20% p.a.	investment:	225.000,00 €

year of operation	1	2	3	4	5	6	7	8	9	10
solar yield kWh/a	311.250	308.760	306.290	303.840	301.409	298.998	296.606	294.233	291.879	289.544
accumulated solar energy kWh	311.250	620.010	926.300	1.230.140	1.531.548	1.830.546	2.127.152	2.421.384	2.713.263	3.002.807
energy price in EUR/kWh	0,07	0,08	0,10	0,12	0,15	0,17	0,21	0,25	0,30	0,36
savings in EUR	21.788	25.936	30.874	36.752	43.750	52.080	61.996	73.800	87.852	104.579
operational costs in EUR	450	450	450	450	450	450	450	450	450	450
accumulated savings in EUR	21.338	46.823	77.247	113.550	156.850	208.480	270.026	343.376	430.778	534.907
account balance in EUR	-203.663	-178.177	-147.753	-111.450	-68.150	-16.520	45.026	118.376	205.778	309.907

year of operation	11	12	13	14	15	16	17	18	19	20
solar yield kWh/a	287.228	284.930	282.650	280.389	278.146	275.921	273.713	271.524	269.352	267.197
accumulated solar energy kWh	3.290.035	3.574.965	3.857.615	4.138.004	4.416.150	4.692.071	4.965.784	5.237.308	5.506.659	5.773.856
energy price in EUR/kWh	0,43	0,52	0,62	0,75	0,90	1,08	1,29	1,55	1,86	2,24
savings in EUR	124.491	148.194	176.410	209.998	249.982	297.578	354.237	421.684	501.973	597.548
operational costs in EUR	450	450	450	450	450	450	450	450	450	450
accumulated savings in EUR	658.948	806.691	982.651	1.192.199	1.441.731	1.739.309	2.093.546	2.515.230	3.017.203	3.614.751
account balance in EUR	433.948	581.691	757.651	967.199	1.216.731	1.514.309	1.868.546	2.290.230	2.792.203	3.389.751

year of operation	21	22	23	24	25
solar yield kWh/a	265.059	262.939	260.835	258.748	256.678
accumulated solar energy kWh	6.038.915	6.301.854	6.562.689	6.821.438	7.078.116
energy price in EUR/kWh	2,68	3,22	3,86	4,64	5,56
savings in EUR	711.321	846.757	1.007.979	1.199.899	1.428.359
operational costs in EUR	450	450	450	450	450
accumulated savings in EUR	4.326.072	5.172.829	6.180.808	7.380.706	8.809.066
account balance in EUR	4.101.072	4.947.829	5.955.808	7.155.706	8.584.066

Advantage:

- Savings increase with energy price surge
- Not depending on government policy
- Stable and predictable energy costs for the solar power

Disadvantage:

- Not as predictable as a feed-in tariff system
- System size has to take demand
- profile into account (avoid solar excess)
- Limited solar fraction, based on daily demand profile without batteries

Information needed prior installation:

- Local feed-in policies and regulations
- Capacity of main or sub-distribution board connection
- Roof area and structure (remaining lifting capacity)
- Shading effects

Necessary components:

- PV area with support structure
- Inverters
- AC connection units
- Batteries
- Charge control (if required)

c) Net-metering systems

A net-metering system is an option to avoid expensive battery solutions by using the public grid as a "free battery". The system is connected to the internal grid of the hotel on a three-phase voltage level. The generated solar power is first used for consumption within the hotel. Any excess is automatically fed into the public grid and compensated usually at the same rate as purchased electricity or at the local feed-in tariff. Therefore, excess solar energy is "charged" to the public grid and consumed on demand similar to a battery bank. To measure the amount of solar energy transferred into the grid a power meter is installed as well as a meter to record the amount of purchased electricity from the grid.

EXAMPLE 10

Net-metering systems

From an economic point of view, a net-metering system can be set equal to a pure self-generating solution. The amount of savings is equal as the compensation of net-metered power. If more power is fed-into the grid than purchased, the surplus can be seen as system profits (i.e. power generation costs of utility).

Advantage:

- Simple sizing
- No detailed demand profile needed
- No batteries required
- Stable and predictable power costs for the generated solar power
- Cost-efficient
- Attractive investment (net profit after pay-back time)

Disadvantage:

- Compensation for net-metering depends on feed-in tariff policy
- Information needed prior installation:
- Capacity of grid connection for feed-in
- Local policies and regulations
- Capacity of main or sub-distribution board connection
- Roof area and structure (remaining lifting capacity)
- Shading effects

Necessary components:

- PV area with support structure
- Inverters
- AC connection units

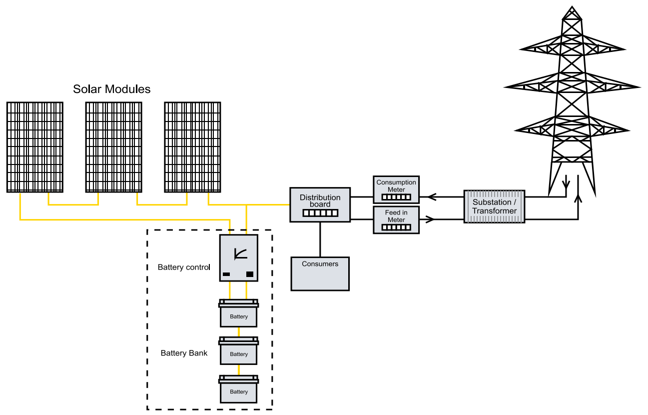


Figure 87: An example of net-metering solar power system

- Metering for feed-in power

2.2.5 STAND-ALONE OFF-GRID SYSTEMS

Solar stand-alone systems are typically used in off-grid situation where no access to a public grid is available. Such installations are often on islands, mountain huts, eco-lodges or other remote vacation destinations. Different from other grid-connected solutions, stand-alone systems require a precise design based on recorded or calculated load profiles. Accurate data is especially needed if batteries are integrated into the system design.

For any system design, aging effects and sediments on the panels have to be calculated to ensure sufficient power supply along the entire lifetime of the system. Due to the fact that in off-grid systems solar energy is the only available energy source, it is important to install high quality components to ensure the reliability of the system. It is best to lower any redundant additions to the design and unnecessary spare part management. Contrarily to off-grid system, in grid-connected solar solutions, there is always the grid available in case of any malfunction, whereas the off-grid hotel depends on the operation of the solar power at all times. Grid-connected systems only need to be economic on the level of the yearly energy balance, while the seasonal profile of solar energy gained is not that important. Stand-alone systems have to be designed with a back-up to ensure daily operations. Therefore, it is crucial for the system design to take the demand profile and the yearly solar irradiation into account.
Accurate design and qualified components is key for a well operating stand-alone solution to satisfy the hotel guests.

To lower any solar waste and thus investment costs, it is beneficial to first reduce the demand profile through the integration of energy-efficient consumers before installing an off-grid system. Also for off-grid systems, aging effects and sediments on the panels, which lower their efficiency, have to be regarded in the system design phase. Thus, to ensure sufficient solar output along the entire lifetime, the systems have to be slightly oversized, for degradation not to lower the performance to a suboptimal level.

In the following section, the basic principles of solar systems for off-grid applications are explained. A mix of different system solutions is also possible, depending on the individual project situation.

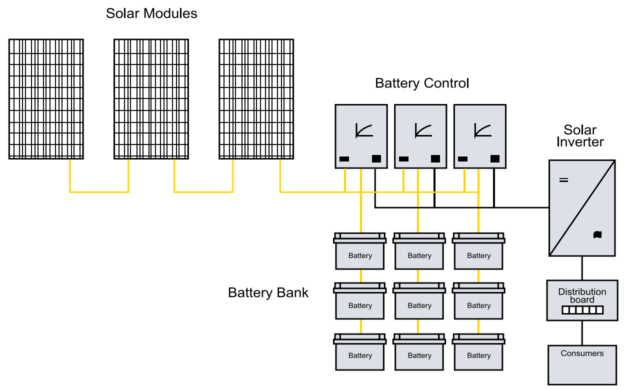


Figure 88: Stand-alone system with batteries

a) Stand-alone systems with batteries

Stand-alone systems with batteries are used in off-grid applications, whenever the solar irradiation profile and the demand profile are somewhat correlating during the seasons and periods of long-term storage of electricity can be avoided. In such cases, batteries are only necessary to balance between daytime solar irradiation and demand during the rest of the day.

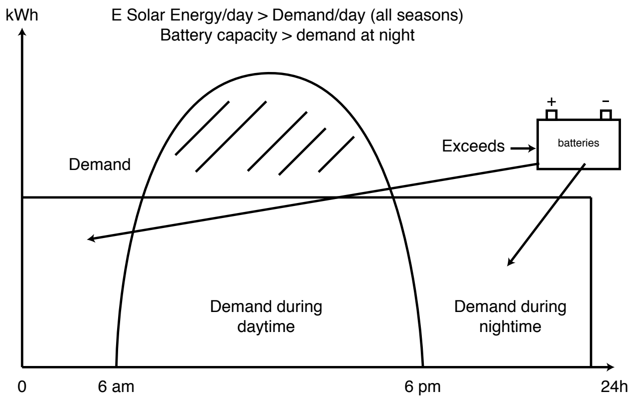


Figure 89: Load profile of stand-alone system with batteries

In stand-alone systems including batteries, the solar system is usually connected to the batteries on DC level via a charge control that stores excess/unused solar power in the batteries. A special island inverter transfers the power from the solar system or the batteries into AC power for the consumers. The system creates its own grid with the required frequency and voltage for the connected consumers. The energy demand profile is entirely supplied by the solar system and no back-up power source is integrated.

When sizing a stand-alone system with batteries, it is important that the solar output design is high enough to charge the batteries in addition to the demand profile during the day in order to secure 24h operations. Further, the inverters used have to provide an independent stable grid that is either operating on batteries or on the solar system directly, depending what energy source is available at the time of the day. To guarantee 24h operations, the batteries must be designed accurately according to the demand profile during non-sunshine hours to ensure necessary capacity, optimal usage and lifetime regarding charging/discharging cycles.

Again, the system size must take aging effects, sediments on the panels, seasonal demand and the irradiation profile into account.

EXAMPLE (SIMPLIFIED) 11

Stand-alone system with batteries

System type: Stand-Alone System with batteries

Location: Camp on Sinai Peninsula, Egypt (old generators are replaced)

Load profile: Constant power demand for 12h=100 kW

Total energy demand: Demand profile is correlating with solar irradiation and power

Existing

Diesel generator:generation at night time is neglected

Total diesel demand: 12 h × 100 kW = 1,200 kWh

Costs of diesel incl. storage 150 kW and transportation: Fuel consumption at partial load of 70% = 27 l/h 27 l/h×12h = 324 l/day 0.20 EUR/l

Daytime demand during sunshine hours: 800 kW

Demand during non-sunshine hours: 400 kWh = minimum battery capacity[1]

Daytime demand during sunshine hours: 800kWh

Demand during non-sunshine hours: 400kWh = minimum battery capacity

Solar yield in Sharm El Sheikh: 5.15kWh/kWp per day
Required size of solar power system: 1,200 kWh / 5.15 kWh/kWp = 233kWp

Cost for solar system: 1,500 EUR/kWp x 233 kWp = 349,200EUR

Costs for battery system: 400 EUR/kWh x 400 kWh = 160,000EUR

Total investment: 509,500 EUR

Savings on Diesel: 365 days×324l/day = 118,260l

Cost savings: 118,260l×0.20 EUR/l = 23,536EUR/year

Cost savings at international diesel price: 157,680×0.80 EUR/l = 94,608EUR/year

Figure 90: Daytime and night time demand vs. solar profile

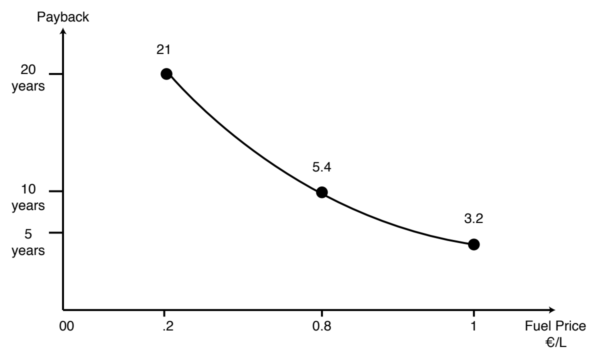


Figure 91: Amortization with different diesel prices (subsidized and international)

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[1] Source: www.globalpetrolprices.com
[2] Example is simplified to show the principles of possible savings

The battery system and size areh best simulated on accurate demand data and solar irradiance to be able to decide if additional battery capacity for daytime usage is possible, as a 100% correlation between demand and irradiance cannot be guaranteed at all times. Also battery performance is influenced by aging effects, sediments and the number of charging/discharging cycles, which therefore have to be included in the sizing of the battery bank.

Advantage:

- No interaction with other power sources
- Completely silent power generation

Disadvantage:

- Sizing possible based on detailed demand profile only (data needed at least on hourly demand)
- High investment and long payback time in case of subsidized fuel

Information needed prior to installation:

- Detailed demand profile
- Choice of best battery technology for specific environmental conditions
- Roof area and structure (remaining lifting capacity)
- Shading effects
- Alternative of hybrid systems

Necessary components:

- PV area with support structure
- Inverters
- AC connection units
- Charge control for batteries
- Island inverters
- Batteries

b) Hybrid systems with a switch operation

Hybrid systems with a switch operation are used in off-grid applications, whenever the 24h demand profile is larger than the maximum possible solar output (incl. batteries). Therefore, the solar output covers the daytime load and the generator supplies the demand during non-sunshine hours. With the help of a switch operator, the system is automatically shifting from solar energy to the generator at times of insufficient solar energy.

When sizing a hybrid system, it is beneficial to size the solar system large enough to cover average daytime demand to avoid frequent switches between the solar system and the generator, which otherwise might lower the efficiency of the generator and decrease energy cost savings. With the use of accurate data on the demand profile, it is possible to design the system to operate the solar side for 8 consecutive hours a day, and thereafter switch to the generator to cover the energy demand for the rest of the day, without any additional switches in between.

Adding the switch operation option to a solar system is only reasonable, when the generator has a flexible control and a wide frequency range in order not to lose efficiency when running on partial loads. If that is given, a hybrid operation with modulating generators (i.e. fuel saver solution) is a more cost-efficient choice compared to a system with batteries.

As in any other solar design, also in a hybrid solution aging effects, sediment residues on the panels and irradiation have to be taken into account. However, contrarily to solar applications including batteries or a grid-connected system, the sizing for a hybrid must be based on the demand profile to ensure daily operations and not on daily or yearly solar energy yield.

For accurate sizing it is important to consider the daily irradiation profile and the demand profile of different seasons, in order to calculate the expected output profile and operating time. The inverters must be able to provide an independent stable grid that is supplied by the solar system directly. Relatively small batteries can be integrated in addition to prolong the solar operation time and to balance deviations between supply and demand during daytime.

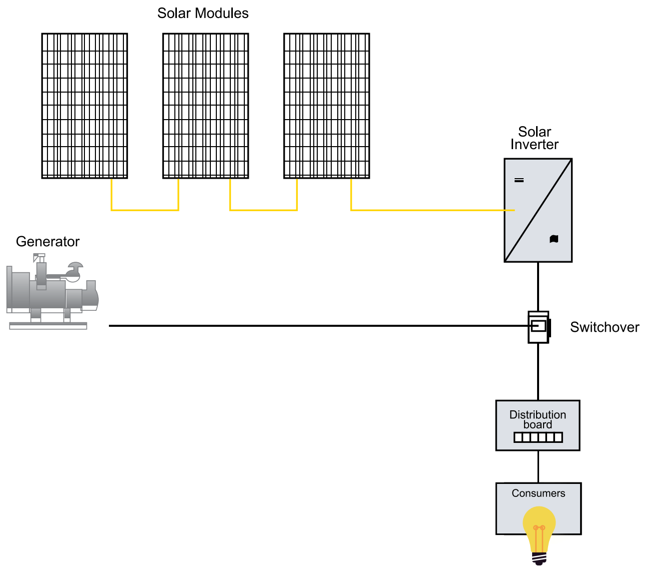


Figure 92: Hybrid system with switch operation

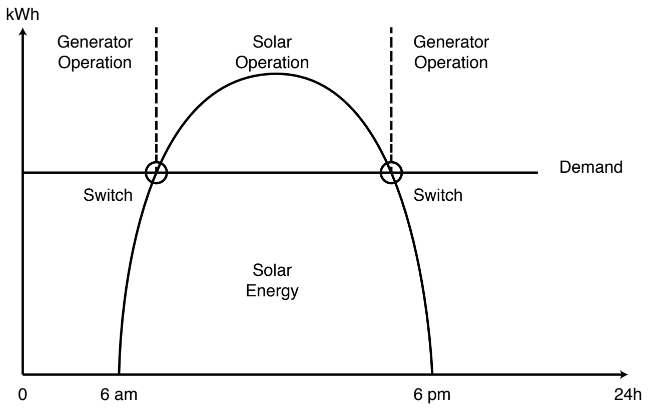


Figure 93: Load profile of a hybrid system with switch operation

Figure 95: Daytime and night time demand vs. solar profile

EXAMPLE (SIMPLIFIED) 12

Hybrid system

System type: Hybrid system for a hotel

Location: Marsa Alam, Egypt (old generators are kept)

Load profile:
Constant power demand of 18 h = 200 kW
Demand profile is correlating with solar irradiation and power generation at night time is neglected

Total daily energy demand: 18 h × 200 kW=3,600 kWh

Existing diesel generator: 250 kW
Fuel consumption at partial
load of 80% = 45 l/h

Total diesel demand without solar system:
45 l/h × 18 h = 810 l/day

Costs of diesel incl. storage and transportation: 0.20 EU-R/l

Required minimum power of solar system:
200 kW during daytime

System size to ensure 8 h operation: 320 kWp[3]

Cost for Solar System: 1,500 EUR/kWp x 320 kWp = 480,000 EUR

Savings on Diesel: 365days x 8 h/day x 45 l/h = 131,400l

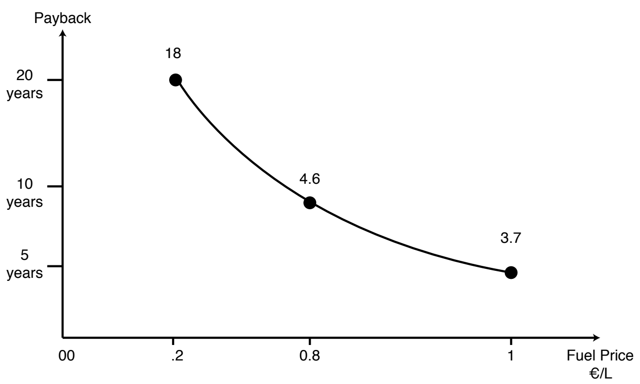


Figure 96: Amortization with different diesel prices (subsidized and real)

Cost savings: 131,40l × 0.20 EUR/l = 26,280 EUR/year

Cost savings on international diesel price: 131,400 × 0.80 EUR/l3 = 105,120 EUR/year

Advantage:

- Easy control
- Existing generators can be used

Disadvantage:

- Oversizing of solar system required
- Daily peaks of solar power generation are lost, if no batteries included
- Limited solar fraction according to ratio of daytime to night time demand, if no batteries included

Information needed prior to installation:

- Detailed demand profile and solar irradiation profile in different seasons
- Roof area and structure (remaining lifting capacity) or available land for installation
- Flexibility of generators and efficiency at different loads

Advantage:

- Easy control
- Existing generators can be used

Disadvantage:

- Oversizing of solar system required
- Daily peaks of solar power generation are lost, if no batteries included
- Limited solar fraction according to ratio of daytime to night time demand, if no batteries included

Information needed prior to installation:

- Detailed demand profile and solar irradiation profile in different seasons
- Roof area and structure (remaining lifting capacity) or available land for installation
- Flexibility of generators and efficiency at different loads
- Generator control
- Shading effects

Necessary components:

- PV area with support structure
- Inverters
- AC connection units
- Island inverters
- Switch control

3 See: Solar Pump Systems in Egypt – Practical Guidelines for Self-Assessment

C) Fuel saver solution

The fuel saver solution for off-grid applications is a suitable system, when the generators or a cascade of several generators allow a flexible control and constant operation on a minimum load, according to the demand profile. In such a system, the operation can shift automatically from 100% solar reliance to only partial solar fraction to a full generator power supply. This requires flexible generators, but also a control system, which can manage both, control of the solar system and the generators.

The control system is needed to ensure, that on the one hand no solar energy is wasted and on the other hand, the generators run smoothly on an acceptable efficiency level to avoid any efficiency losses. The aim of the fuel saver solution is to generate the most cost-efficient balance between the use of solar energy and generators.

Compared to the previous solar systems, the fuel saver option is not as affected by aging and sediment residues, as long as the flexibility of the generators is assured. The inverters have to be able to create their own grid, whenever the use of solar energy is larger than that of the generator. Only in cases in which the solar ratio is small, in a range of up to 20-30%, the inverter does not need to create its own grid, as the generator has to operate on a constant level, serving as the grid connection of the system. However, if solar energy becomes the dominating or at times only power source, island inverters have to be integrated, which require a control option and more complex system design.

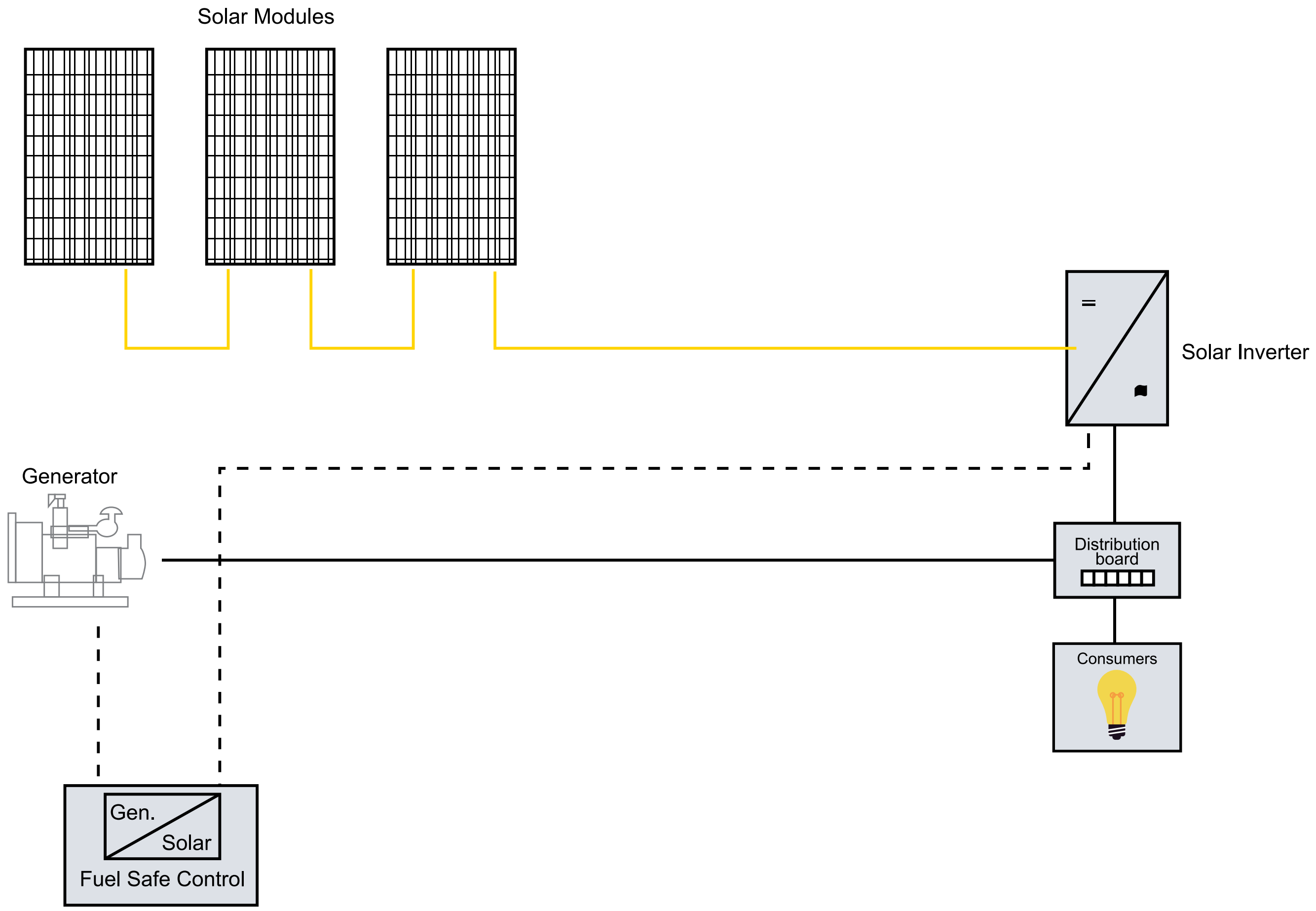


Figure 97: Fuel saver solution

Figure 98: Daytime and night time demand vs. solar profile

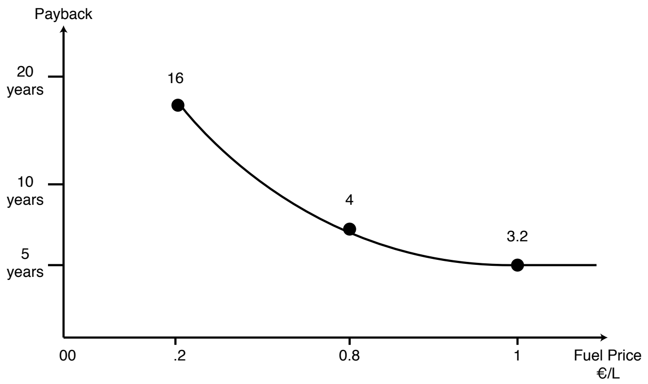


Figure 99: Amortization with different diesel prices (subsidized and real)

EXAMPLE (SIMPLIFIED) 13:

Fuel saver solution

System type: Fuel saver solution for a hotel

Location: Marsa Alam, Egypt (new project with flexible generators)

Load profile: Constant power demand at 18 h = 200 kW

Demand profile is correlating with solar irradiation and power generation at night time is neglected

Total daily energy demand: 18h × 200kW = 3,600kWh

Demand during daytime: 8h × 200 kW = 1,600 kWh

Existing diesel generator: 250 kW Fuel consumption at partial load of 80% = 45 l/h

Total diesel demand without solar system: 45 l/h × 18 h = 810 l/day

Costs of diesel incl. storage and transportation: 0.20 EU-R/l

Target: 25% savings on diesel costs equal to 328,500 kWh

Solar yield in Marsa Alam: 5.6 kWh/kWp per day

Required size of solar power system: 328,500 kWh/365 days + 1/5.6 kWh/kWp = 160 kWp (80% of power de-mand)
Cost for solar system: 1,500 EUR/kWp x 16 kWp = 240,000 EUR

Savings on diesel: 0.25 × 810l = 202 l/day

Cost savings: 202 l/day × 365 days x 0.20 EUR/l= 14,748 EUR/year

Cost savings on international diesel price: 202l /day × 365days x 0.80 EUR/l = 58,984 EUR/year

Solar yield in Marsa Alam:

Required size of solar power system: 25% savings on diesel costs equal to 328,500 kWh
5.6 kWh/kWp per day

Cost for solar system: 328,500 kWh/365 days + 1/5.6 kWh/kWp = 160kWp (80% of power demand)

Savings on diesel: 1,500 EUR/kWp x 16 kWp = 240,000 EUR 0.25 × 810l = 202 l/day

Cost savings: 202 l/day × 365days x 0.20 EUR/l= 14,748 EUR/year
Cost savings on: 202l /day × 365days x 0.80 EUR/l4= 58,984 EUR/year

International diesel price: 202l /day × 365days x 0.80 EUR/l = 58,984 EUR/year

Advantage:
- Higher efficiency in hybrid operation than switch operation
- Easier sizing
- No oversizing of solar system and no loss of peak output

Disadvantage:
- Flexible generators required
- Higher investment for control system

Information needed prior to installation:
- Roof area and structure (remaining lifting capaci-ty) or available land for installation
- Flexibility of generators and efficiency at different loads
- Check if island inverters are necessary
- Generator control
- Shading effects

Necessary components:
- PV area with support structure
- Inverters
- AC connection units
- Island inverters if required
- Fuel saver control

3 See: Solar Pump Systems in Egypt – Practical Guidelines for Self-Assessment

2.3 HEAT AND POWER HYBRID CO-GENERATION

Hotels usually require both – heat and power – to satisfy total energy demand. Therefore, it can be reasonable to combine the solar power and thermal technologies in a combined heat and power generation (CHP) unit (figure 100).
There are two options to operate a CHP unit. The first option is to operate it on power for as long as power is generated, which means the load of the generator depends on the actual required power and heat. The second option is to operate the system on heat, which means the load of the generator depends on the required heat, whereas the generated electricity is only used on demand. Generally, CHP system's output has a fraction of around 50% heat and 50% power. Temperatures on the thermal generation side are usually in a range of 85-90°C. The heat is used for any conventional hot water device, but also for higher temperature applications, such as laundry or pool heating systems.
There are two options to operate a CHP unit. The first option is to operate it on power for as long as power is generated, which means the load of the generator depends on the actual required power and heat. The second option is to operate the system on heat, which means the load of the generator depends on the required heat, whereas the generated electricity is only used on demand. Generally, CHP system's output has a fraction of around 50% heat and 50% power. Temperatures on the thermal generation side are usually in a range of 85-90°C. The heat is used for any conventional hot water device, but also for higher temperature applications, such as laundry or pool heating systems.

Figure 100: Combined Heat and Power unit

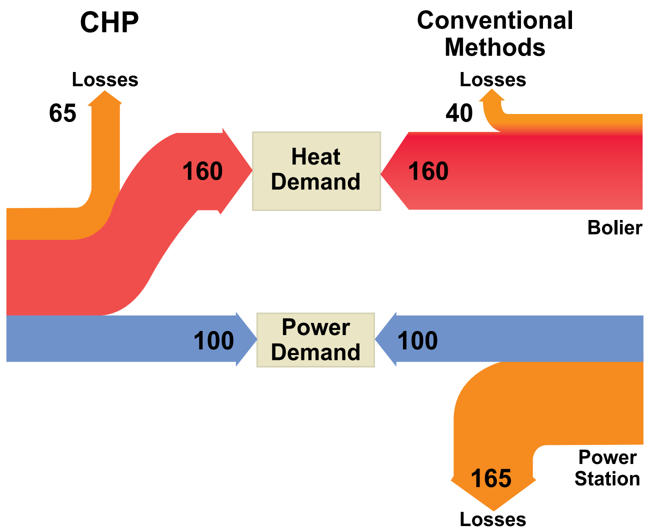


Figure 101: Principles of CHP generation units

EXAMPLE 14

Diesel generator vs. CHP
Demand assumption: Constant demand during 24h

A) Diesel generator

Required capacity of generator	120 kW	Efficiency of generator:	45%
Input of generator:	270 kW	Operating time:	24h/day
Diesel consumption per day:	640 l/day		
Power output:	2,880 kWh/day		
System efficiency:	45%		

B) CHP based on same power output

Thermal efficiency:	41%	Electrical efficiency:	39%
Required power:	120 kW	Input of generator:	310 kW
Operating time 24h/day			
Diesel consumption per day:	744 l/day		
Power output:	2,880 kWh/day		
Heat output:	3,050 kWh/day (enough to heat up 65m³ of hot water per day)		
Total output:	5,930 kWh/day		
System efficiency:	80%		

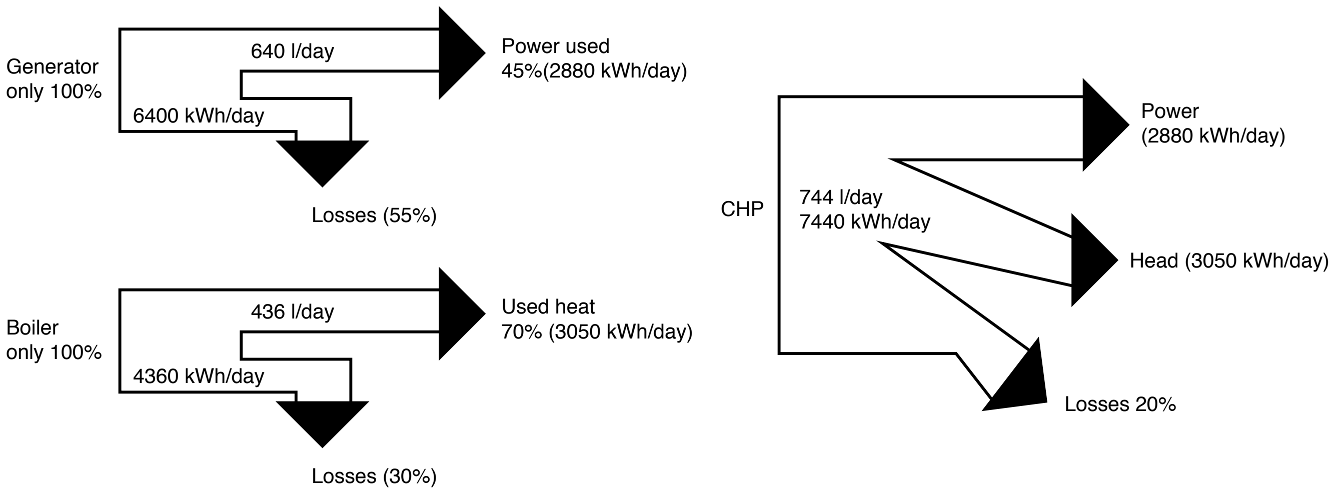


Figure 102: Daytime and night time demand vs. solar profile

In case of a CHP unit with a conventional boiler (efficiency 70%) to heat up the same amount of water a day, additional 436 litres of diesel would be necessary daily.

The total comparison of the energy balance would be:

Generator + Boiler
Input: 640 l/day for power + 436 l/day for heat = total 1,076 l/day

Output: 2,880 kWh electricity + 3,050 kWh heat = 5,930 kWh

Total Efficiency: 55%

CHP:
Input: 7,44 l/day for power and heat

Output: 2,880 kWh electricity + 3,050 kWh heat = 5,930 kWh

Total Efficiency: 80%

Savings by CHP: 332 litres of diesel = 30% of diesel consumption

Advantage:
Higher system efficiency
Higher generator efficiency
Less fuel consumption
The application is reasonable and economic, if heat and power are required at an equal rate across the year. Depending on the demand profile and fractions of heat and power on the total demand, the following combinations are applicable:

A) Hotels with higher heat demand than power
For hotels with a higher heat than power demand, a combination of a solar thermal system in addition to a CHP is a reasonable solution, especially for hotels using diesel generators as their main power supply. The generated heat can either be used to support the solar thermal system or any other thermal applications, such as pool heating.

The CHP is operating based on the actual power demand and the generated heat is used for hot water. The solar thermal system provides any additional needed thermal energy and a conventional back-up boiler, if required. These applications are especially suitable for hotels with high heat demand for pool heating or wellness facilities (e.g. spa hotels), which is otherwise covered by boiler systems.

A) Hotel with higher power demand than heat
For hotels with a higher power demand than heat, a combination of solar power a CHP generator is reasonable. The degree of its economic feasibility depends on the demand profile and whether the hotel is relying substantially on generators. The power from CHP can be used for the support of the solar power system.

The CHP is designed based on the power demand. However, any additional power needed to surpass peak demands can be provided by a back-up generator or the grid, if available. In case of additional heat, a conventional flexible boiler can be integrated. This application is especially suitable for hotels with high power demand and less heat demand, such as business hotels.

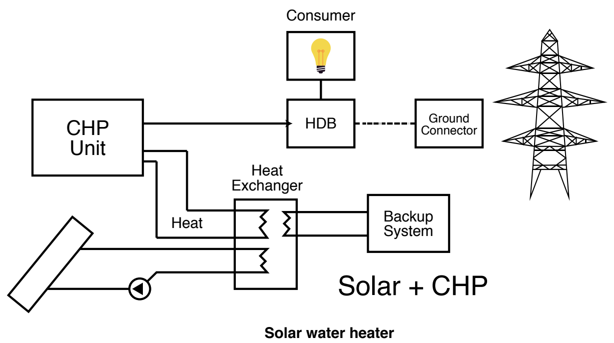


Figure 103: CHP Generators + Solar thermal

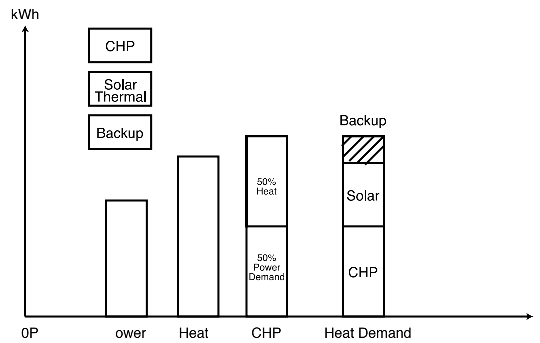


Figure 104: Demand profile and fractions of solar thermal and CHP + back-up

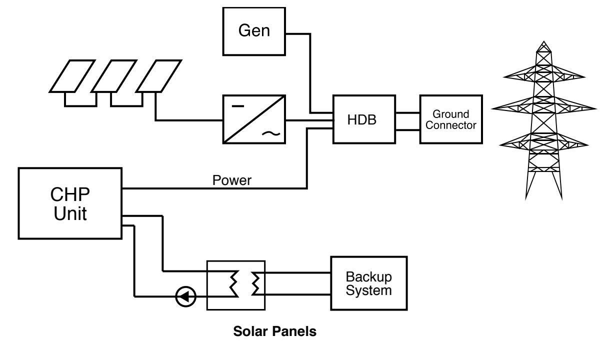


Figure 105: Combined Heat and Power Generators + Solar Power

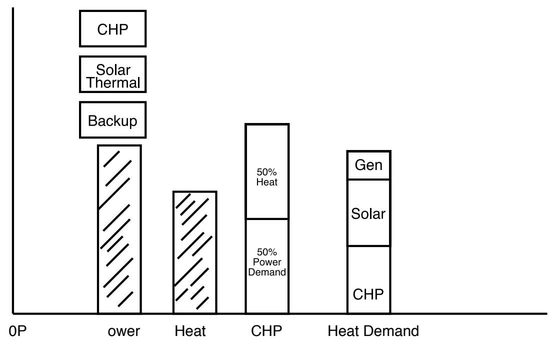


Figure 106: Demand profile and fractions of solar power and CHP + back-up

03

THE ENERGY DEMAND OF HOTELS

Chapter Three

The main energy consuming activities in a hotel are:

- Hot water use
- Air-conditioning for rooms and public facilities
- Energy intensive facilities (e.g. kitchen, laundry, spa facilities)
- Swimming pool heating
- Lighting for rooms, facilities and special applications

Energy saving initiatives is important in the hotel sector, as they can drastically lower the operating expenses. The highest single energy consuming application in hotels is space conditioning (e.g. heating/cooling, ventilation, air-conditioning). It accounts for approx. half the total energy consumption. Outdoor weather conditions, floor areas and indoor temperatures are among others, the main factors influencing the energy consumption in hotels.

Domestic hot water is commonly the second largest user, accounting for up to 15% of the total energy demand. Lighting can fluctuate between a range of 12-18% or even up to 40% of a hotel's total energy consumption, depending on the hotel type. Services such as catering and laundry also account for a considerable share of the load profile, particularly considering that they are commonly the least energy-efficient. Moreover, sports and health facilities are typically high-energy consumers. Similar results have been reported by studies of Greek hotels, which confirm that approx. 72-75 % of the total energy consumption is used for space conditioning and hot water consumption. Far less is spent on lighting with a share of 8-9 % and 15 % on catering.

However, each hotel is different and the power as well as hot water demand cannot be determined by global statistics only. Values from studies may help to identify general demand figures at the early stage of a project or foremost assist in benchmarking energy consumption and efficiency of ones own hotel to others from the region.

To design a solar system, regardless of a power or thermal application, it is essential to know or calculate the individual demand profile, not only on average, but also including seasonal influences and fluctuations in occupancy.

For existing hotels, it is recommended to integrate meters for power, heat and water, at least on the total level of consumption.

- Flow meters for cold water consumption
- Heat meters for flow rate and temperatures for hot water applications
- Power meters for electricity consumption

Metering and monitoring the demand on flow, heat and power can be either done online and fully automated or manually by reading off the meters and monitoring them.

Figure 107: Flow-, heat- and power meter

Metering is only a small investment, but allows great savings once the data has been recorded. Wireless solutions are already available at affordable prices. Of course, the more detailed the metering, the more valuable the information, as it is used as the basis for designing a solar system or to optimize existing energy flows. Only if the water and energy flow is known, solid decisions for changes can be made.

The following data should be collected on the total level or better on the level of different sections or categories within the hotel (e.g. power for rooms, facilities, air-conditioning):

- Flow rates (litres or m^3/h) and daily demand (litres or m^3/day) of total cold water supply
- Flow rates (litres or m^3/h), daily demand (litres or m^3/day) and temperatures (°C) for hot water demand with inlet and outlet temperatures in case of closed circuits with heat exchangers
- Power demand (W) and energy consumption (kWh)
- Fuel consumption based on fuel sourcing for boilers or generators (litres/day/month)

If no metering is available, it is possible to calculate the energy demand based on a complete list of consumers, according to their specific demand and operating times. As a result, the total energy demand is calculated by adding the calculated consumption of each unit separately. This method is time consuming and not as accurate as metering. In any case, the results of the calculation must be rechecked with the total energy demand based on fuel and power supply, prior to optimizing the energy system and integrating a solar application.

For new designed hotels, it is more challenging to calculate and create the theoretical demand profile, as the calculation has to be made based on assumptions regarding occupancy, behaviour of users, etc. As a first step, it is best to list all energy consumers in different categories, such as lighting and air-conditioning and add their assumptions according to the daily operating time in different seasons. It is also helpful to distinguish end-consumers between the ones that correlate with the occupancy rate from the ones that have a steady consumption profile yearlong.

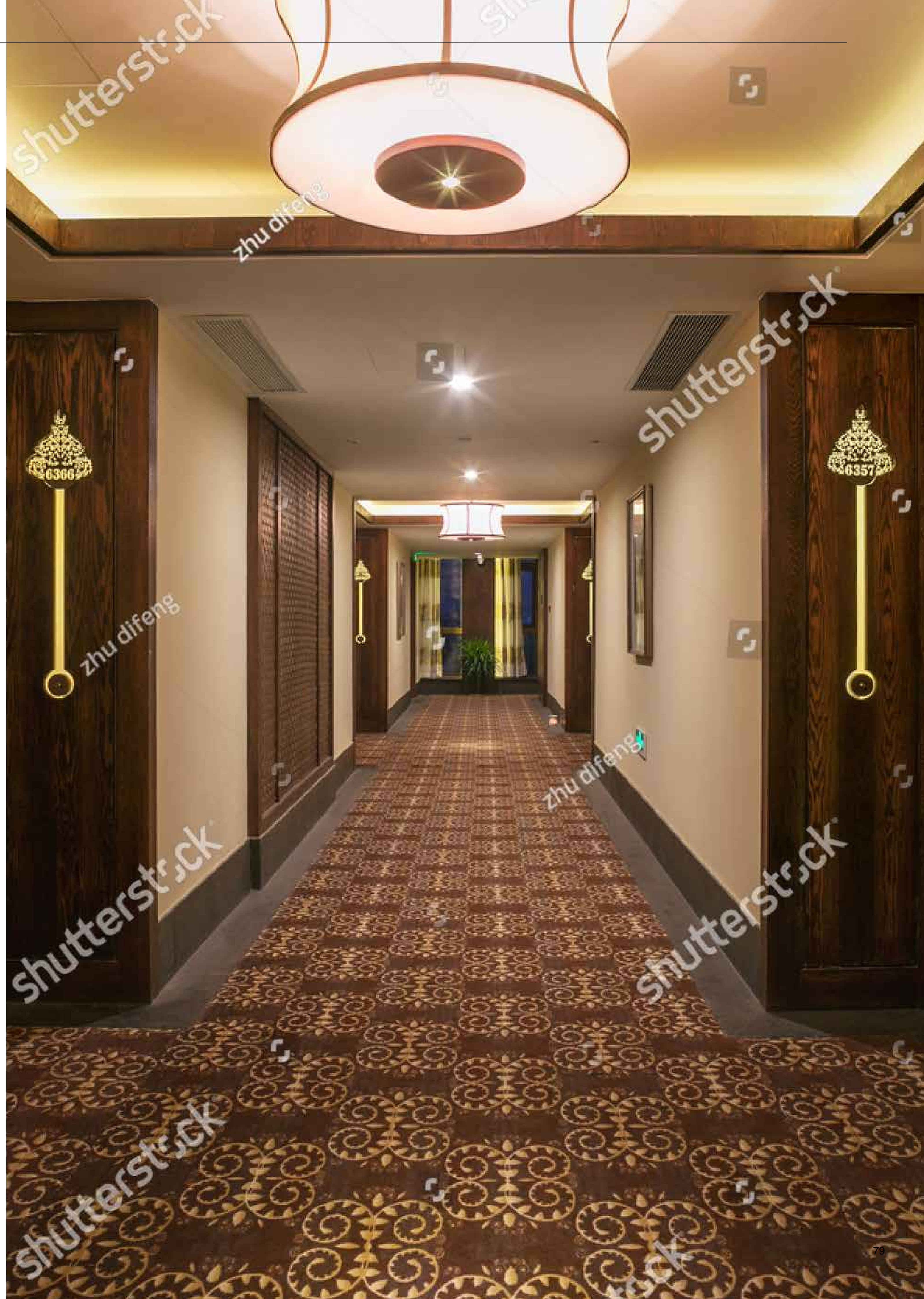


Table 2: Sample date sheet to calculate the demand profile

Determination of hotel power demand profile

Average occupancy rate (%)		Number of Guest Rooms:	

Consumer Group	Consumer	Power (W)	Description	Start time (hh:mm)	Stop Time (hh:mm)	Operating Time* (h)	Operating at peak	Demand factor**	Peak power demand (W) ***	Energy demand p. day (kWh)****	Energy demand per year (kWh)
		Type Plate or Marking	(e.g. 2 LED bulbs with 15 W)	For Regularly Operating Devices			Yes/No				energy demand p. day x 365
Guest Rooms	Fridge										
	TV										
	Air-conditioning										
	Bathroom light										
	Bed light										
	Room light										
	Table light										
Outdoor Light	Lighting for ways							1			
	Golf area							1			
	Hotel entry							1			
	Other outdoor light							1			
	Other							1			
Facility Lighting	Reception							1			
	Floors							1			
	Common rooms							1			
	Restaurants							1			
	Pool bar							1			
	Pool lighting							1			
	Other							1			
Facilit ies	Reception							1			
	Office							1			
	Computer							1			
	Printer							1			
	Server and Telecom							1			
	Air-conditioning							1			
	Laundry - washing										
	Laundry - dryers										
	Kitchen - cooking							1			
	Cold storage							1			
	Hot water system							1			
	Ventilation system							1			
	Elevators							1			
	Gym							1			
	Wellness and Spa center							1			
	Other							1			
Heating System	Boiler							1			
	Pumps							1			
	Circulation pumps							1			
	Electric heaters										
	Water treatment										
	Other							1			
								Peak Power demand		W	
								Σ Peak Power Demand			
									Energy demand per day		kWh
									Σ Energy Demand P. Year		
										Energy Demand Per Year	

* Assumption or (Stop time - start time) if available
** Number of guest rooms x occupancy rate for consumers depending on number of guests 1 for others
*** Power (column 3) x demand factor if operating at peak time
**** Operating time x power demand x demand factor

As a result, there should be a daily and seasonal demand profile linked to occupancy, before designing a solar system. Further, the base demand that is independent from the number of guests and consumers has to be known, to verify the minimum energy consumption.

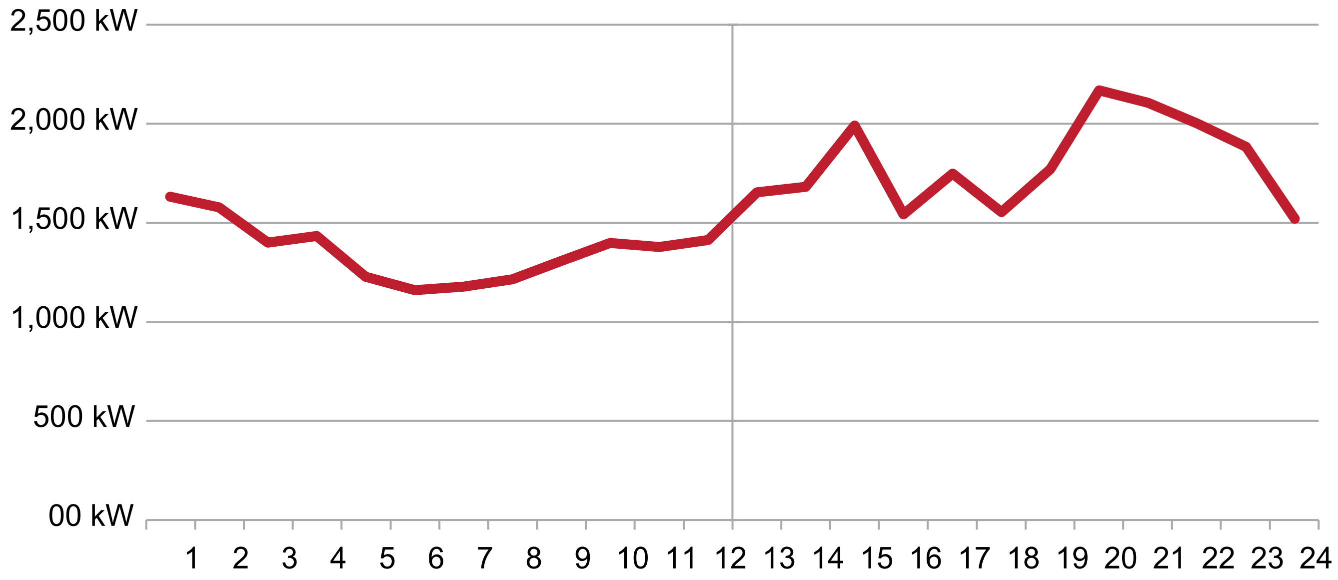


Figure 108: Sample of a daily demand profile of a hotel in Marsa Alam, Egypt

3.1 TYPICAL CONSUMERS

3.1.1 LIGHTING

Electric lighting can be responsible for up to 15% of the total energy consumption of the hotel and even more in hotels with special lighting applications, such as golf areas and sport facilities that are lit at night.

New technologies (e.g. LED lighting) allow remarkable savings in the electricity consumption for lighting. For instance, through the switch from traditional light bulbs or halogen spots to LED lighting, 80% of the energy consumption for lighting can be saved. Even in the case of existing energy saving light bulbs, through LED lights the energy consumption can be reduced in half. To analyse the demand and opportunities to reduce the energy demand for lighting, it is helpful to make a list of lamps with the actual power demand per unit (W), the technology used (e.g. traditional, LED, etc.), and the measured or assumed operating time.

The focus is to replace the units with the longest operating times and oldest technologies first, as these influence the savings the most and therefore have the shortest pay-back times. Especially for units with independent demand (e.g. outdoor lighting) is a great opportunity to save energy costs, in particular in times of low occupancy. Regarding room lighting, it should be firstly verified, whether the installed quantity and power can be reduced via energy saving technologies, without negatively influencing the comfort level of the guests through a change in light colour. Another option is to include special control mechanism, such as movement sensors, time switches, or dimming devices that only consume energy on actual demand. Such technologies are available at affordable prices and equal standards.

Special pools lighting or large outside areas require special attention. Independent small solar lights are a great solution to lower the energy consumption for outside lighting. The design for the independent solar lights should be according to expected light colour, required light intensity and light atmosphere. There are different types of solar light available and therefore each hotel has the opportunity to choose the ones most suitable for its atmosphere.

Table 3: Lighting and typical operating times in hotels

Illuminant (tubes/flood lights/lamps/bay light)	Quantity	New LED power (W)	Old power (W)
LED lamp E27	60 pcs	6	60
LED lamp E27	2135 pcs	4	40
LED lamp E14	0 pcs	4	40
LED Spot MR-16	502 pcs	5	50
Gigalicht Pool Spot 54 W (replace 300W)	0 pcs	54	300
Tube 120 cm (LED 19W/before 40W)	209 pcs	19	40
Tube 60cm (LED 10W/before 22 W)	197 pcs	10	22

Illuminant (tubes/flood lights/lamps/bay light)	Operating hours per day	Days per week	Weeks per year	Total operating hours	New consumption with LED in kWh p.a.	Old consumption in kWh p.a.
LED lamp E27	10	7	52	3640	1310	13104
LED lamp E27	8	7	52	2912	24868	248685
LED lamp E14	8	7	52	2912	0	0
LED Spot MR-16	6	7	52	2184	5482	54818
Gigalicht Pool Spot 54 W (replace 300W)	10	7	52	3640	0	0
Tube 120 cm (LED 19W/ before 40W)	8	7	52	2912	11546	24344
Tube 60cm (LED 10W/before 22 W)	8	7	52	2912	5373	12621
Total				3016 hours	48961 kWh	353572 kWh

EXCURSION 6

Lux and Lumen
The lumen (symbol: lm) is the unit of luminous flux. It is a measure of the total quantity of visible light emitted by a lamp, which is indicated on the datasheet of the lamp. The lux (symbol: lx) is the unit of light and light remittance, measuring luminous flux per unit area in a certain distance to the lamp. It is equal to one lumen per square metre.

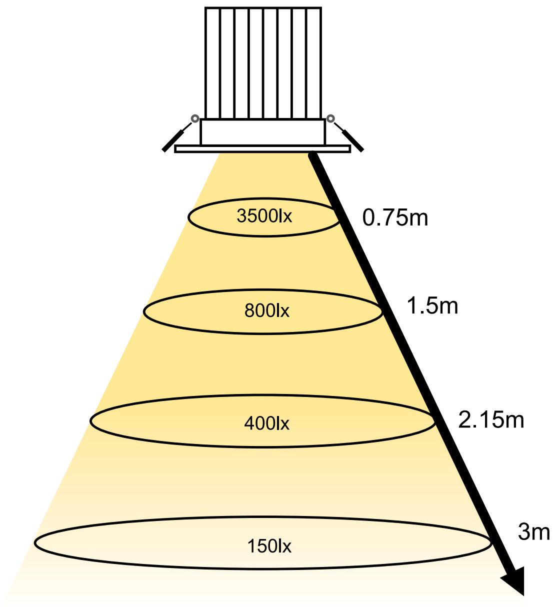


Figure 109: Lux and Lumen

EXAMPLE 15

Replacement of existing 90 Osram HQL 2000W lights by high efficient LED spots with 250W:

Operating time: 6 pm to 1 am = 7 h/day

Consumption with HQL lamps: 1,260 kWh/day = 459,900 kWh/year

Consumption with LED Spots: 158 kWh/day = 57,670 kWh/year

Savings: ≥ 85 %

3.1.2 HOT WATER

When determining the hot water requirements for hotel consumption, the different types of end-consumers have to be taken into account. The daily consumption per occupied bed consists not only of the room-based consumption, but also partially of the number of guests utilising the kitchen and any additional tap connections (e.g. utility rooms, leisure or fitness equipment, etc.). Using the consumption values in figure 110, the daily consumption of a single guest can be determined with the following equation:

EQUATION 1:

$C_{GUEST}=C_{Bed} + C_{Bf} + C_{M} \times (\varepsilon_{HB}+2\times\varepsilon_{FB}) + C_{Sur}$ (l/d)

C_{Bed} Consumption per bed

C_{Bf} Consumption in kitchen per breakfast

C_{M} Consumption in the kitchen per warm meal (lunch/dinner)

C_{Sur} Additional consumers in utility rooms (washing machines,) and/or

fitness-related equipment (showers, whirlpools, saunas,)

ε_{HB} Percentage of customers with half board [% / 100]

ε_{FB} Percentage of customers with full board [% / 100]

(the percentage of customers of restaurant operation with additional daily customers can also be more than 100%)

Consumption type	Hot water requirement per day and person at a temperature of 60°C	
	Average	from - to
Hotel (**-***)	50	30 - 80
Hotel (**** - *****)	80	80 - 150
Guest house, inn	30	20 - 50
Holiday house	40	30 - 50
Camping site	20	15 - 35
Youth hostel,holiday hostel	20	15 - 30
Student hall of residence	25	15 - 60
Retirement home	45	30 - 65
Kitchen - breakfast	2	2 - 3
Kitchen - noon/evening	5	4 - 8
Swimming pool - public/private	40 / 20	
Sauna - public/private	70 / 35	
Hospital	80	60 - 120
Sports facilites - total		35 - 50
Sports facilites - showers	25	20 - 30

Figure 110: Hot water consumption in hotels per day and person

EQUATION 2:

Utilisation $\alpha\_S = nB / (\text{Number of the days observed} \times n)$

n Number of available beds
nB Number of beds in use (overnight stays) during the time of observation (May to August).

A representative amount of the daily hot water consumption for the summer months can be calculated with the consumption equation (equation 3), which plays a crucial role in sizing the collector surface area.

EQUATION 3:

$CSummer = CGuest \times \alpha s \times n$ (l/d at 60°C)

CSummer Total daily hot water consumption in the tourism industry during the time of observation
CGuest Daily hot water consumption of an average guest
αs Average utilisation during the time of observation (May to August)
n Number of available beds

The total daily energy requirement for hot water production can be calculated according to the daily hot water consumption of the object to be supplied (equation 4).

EQUATION 4:

$Q_{HW} = C\ Summer \times cp \times dT\ (THW - TCW)$ [kWh]

Where:
Q_{HW} Daily heat quantity for the entire supply of the object with hot water in kWh
C_{Summer} Daily hot water consumption per guest in litres
Cp Specific heating capacity of water (4.2KJ/kgK)
ΔT Temperature difference between hot water and cold water in Kelvin (e.g. 50K)
T_{HW} Hot water temperature in °C (e.g. 60°C)
T_{CW} Average cold water temperature in °C (e.g.10°C)

3.1.3 CIRCULATION

The amount of water lost in the circulation is almost always underestimated. The power dissipation of well-insulated circulation pipes is approx. 8 W/m, given the pipeline runs inside the building or on well-insulated outer walls. For less well-insulated pipes, at least 10 W/m or more are accepted. In case of wall and ceiling breakthroughs to a boiler house with an insulation of half the thickness, additional 10% of losses should be calculated. However, for well-insulated circulation piping the following equation holds:

EQUATION 5:

Qcirc. = (length circ. × 8 W/m) x 1.1

Digression circulation

For an insulated pipe with a thermal conductivity of 0.035 W/m2K, the heat transfer coefficient kR results in 0.20 W/mK. To determine the circulation losses, the temperature difference between the fluid temperature in the circulation line and the environment can be assumed to be approx. to 40 K[1]. The power losses of a circulation lin e per meter are calculated as follows:

Qcirc. = kR × deltaT = 0.2 W/mK × 40 K = 8 W/m

The worse the thermal conductivity and the thinner insulation, the larger the temperature difference between the fluid and the environment. Hence, the worse the insulation of the circulation pipelines, the more losses are incurred. In fact, the heat losses can be 2-3 times higher, if the tube is not isolated at all.

Table 4: Heat transfer coefficient

Nominal width	Heat transfer coefficient kR [W/mK]			
	Without insulation	50%	100%	200%
DN 10	0.35	0.22	0.173	0.133
DN 15	0.493	0.24	0.18	0.134
DN 20	0.637	0.253	0.184	0.134
DN 25	0.78	0.262	0.186	0.135
DN 32	0.98	0.271	0.189	0.135
DN 40	1.209	0.278	0.191	0.135

1 K = Kelvin

3.1.4 AIR CONDITIONING

In hotels air-conditioning for rooms and facilities is the biggest energy consumer. In fact, air-conditioning causes 50% of the total energy demand and more, especially in geographical areas of hot and arid climates (e.g. MENA-region). Therefore, it is important to design the air-conditioning applications as efficient as possible in order to avoid frequent maintenance check-ups. Thus, energy savings through solar applications are especially high for hotels with constant reliance on cooling systems.

The principle of the air-conditioner remains, regardless of the scale or whether they are centralized or decentralized units. The heat in the room is used to evaporate a liquid in the closed circle of the unit. A compressor is pushing the vapour to a higher-pressure level to condensate on the ambient air conditions at the re-cooling unit, which is installed outside at the building. The liquid is then returning to the evaporator in a continuous process.

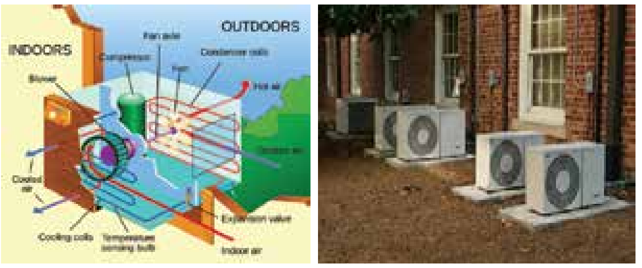


Figure 111: Air-conditioner split unit

The air-conditioner coefficient of performance (COP) describes how much heat in kWh can be transferred to the outside, using 1kWh of electricity.

EXAMPLE 16

Air-conditioning

It is assumed that the COP cooling is at 2.9 and the cooling unit with cooling capacity at 2.9 kW.

Electric power demand: 1.0 kW

Operation time: 24 h/day

Electrical consumption: 24 kWh/day

The operating time of air-conditioning units can reach up to 24h. If no control mechanisms, such as presence control in combination with power reduction, are in place, there is a high risk that air-conditioners keep on running on full capacity 24h. Smart control can help to avoid unnecessary operation and waste of energy. The efficiency of the systems depends on the gap between the inside temperature and outside ambient temperature at the re-cooling unit.

It is therefore possible to reduce the energy consumption in 2 ways:

1. Reduce outside temperature by avoiding direct sunshine on the re-cooling units using shading covers or installing it in shaded area
2. Limit inside temperature at the thermostats to a minimum of 24-26°C

Passive measures through the installation of high quality windows with lower energy transmission, can reduce the need for cooling of the rooms significantly. Further, to lower the need for cooling, internal loads have to be minimized by reducing the power of lamps. A conventional light bulb transfers 10% of their power into light and 90% into heat.

To get a clear picture of the hotel's demand profile as well as their status on air-conditioning, it is recommended to make temporary measurements in individual rooms and/or facilities at random times to observe the actual demand and operating times. A list of air-conditioners in use with the data on their capacity, type and age as well as assumptions on operating times assist in establishing a basis of the load profile of the hotel, which is needed to design a solar power system.
Central air-conditioning units used in modern hotels or centralized facilities allow a much easier monitoring and control of energy consumption and operating time. With a simple meter added to the device, all necessary information is provided.

3.1.5 SWIMMING POOL

Pool heating is especially suitable for the use of solar technology as the pool water only requires relatively low temperatures of approx. 22-25 °C for an outdoor pool and 26-30°C for an indoor pool. Depending on the location of the hotel whether the pool is accessible yearlong, outdoor pools can have the benefit of only requiring solar energy during summer months.
A swimming pool loses the vast majority of its heat at the water surface.

This depends primarily on:

- Water temperature (ϑW)
  - The higher the water temperature (ϑW), the greater the losses through evaporation
- Air temperature (ϑL)
  - The greater the temperature difference (ϑW–ϑL), the higher the losses
  - In indoor pools, the air is generally 1-3K warmer than the water
- Relative humidity
  - The drier the air above the water surface, the greater the losses through evaporation
  - In indoor pools, the relative humidity is between 55% and 65%
- The surface area of the swimming pool

Determination of Demand Profile for Air Conditioning

average occupancy rate: % **number of guest rooms:**

Consumer Group	Consumer	Power W type plate or marking	Description e.g. spilt unit	Start time hh:mm for regularly operating devices	Stop Time hh:mm	operating Time* h	Operating at peak yes/no	demand factor** -	peak power demand *** W	energy demand p. day**** kWh	energy demand per year kWh energy demand p. day x 365
guest rooms											
	air con										
facilities	air con restaurant										
	air con kitchen										
	air con reception										
	air con gym										
	air con else										

Peak Power demand W
Σ peak power demand

* assumption or (Stop time - start time) if available

** number of guest rooms x occupancy rate for consumers depending on number of guests 1 for others

Energy demand per day kWh
Σ energy demand p. day

*** Power (column 3) x demand factor if operating at peak time

Energy demand per year kWh
Σ energy demand p. year

**** operating time x power demand x demand factor

Figure 112: A sample date sheet to calculate the demand profile for air-conditioning

To reduce these losses, it is best to cover the pools at times when it is out of use.
Swimming pool heat losses are due to:
1. Convection
2. Evaporation
3. Heat radiation
4. Heat conduction

3.1.6 FACILITIES

The demand for facilities (e.g. kitchen, laundry, SPA areas, etc.) has to be predetermined according to either recorded data from the meters or consumer lists with power and heat demand for each device and operating time. The hot water demand can be calculated based on data of used machines or for new appliances based on the expected demand profiles.

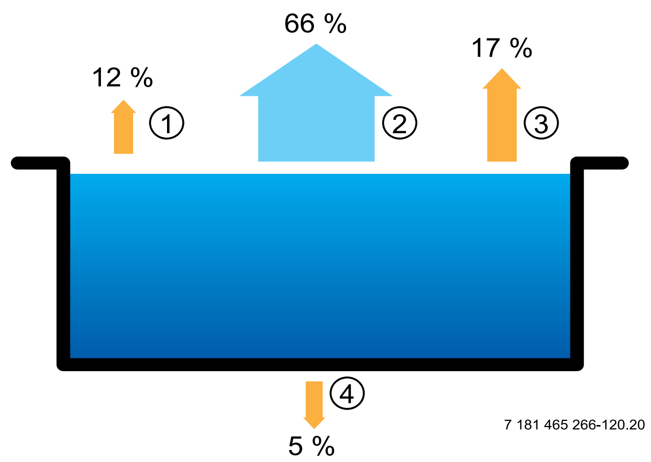


Figure 113: Swimming pool heat losses

3.2 BASIC AND PEAK DEMAND

Nearly all hotel types have a clear morning peak between 7 and 8 o'clock. Within this period about 20% of the total daily hot water demand is tapped. Further, most hotels also have an evening peak, but it is often less pronounced and over a longer period of time. The maximum hourly peak also depends on the type of hotel guests. Tourist hotels have different peak times compared to business hotels in the city. They might have a similar morning peak, but often have a much wider evening peak (figure 11).

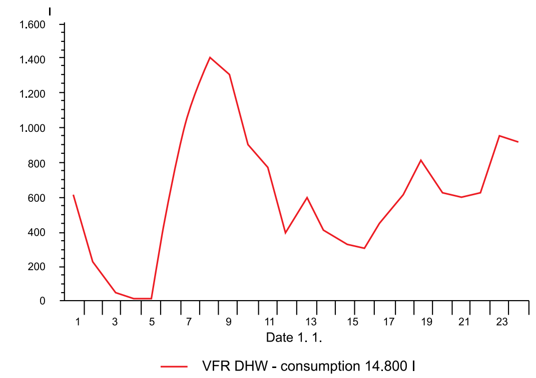


Figure 114: Daily profile of a city hotel

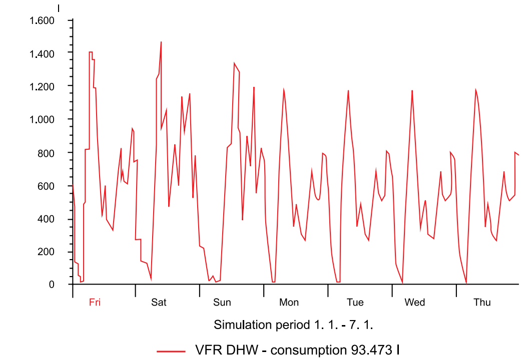


Figure 115: Weekly profile of a city hotel

Figure 116: Yearly profile of a city hotel

3.3 ENERGY SAVING TECHNOLOGIES

Hotel energy consumption is influenced by physical and operational parameters. The physical parameters common to most buildings include size, structure, design and geographical area of the hotel. Moreover, the facility age, energy type and cost, water systems as well as energy and water resources available at the location can affect the amount of energy consumed.

Operational parameters that influence the energy use in hotels include operating schedules for different functional facilities, the number of facilities, services offered, fluctuation in occupancy levels, variations in customer preference, on-site energy conservation practices, as well as cultural and awareness of resource consumption among personnel and guests.

A large proportion of the high-energy consumption in hotels is due to losses and waste. For instance, guests are frequently given full control over thermostat settings and individual air-conditioning units, which are adjusted with little or no concern toward energy consumption. Often windows and doors are opened, whilst cooling or heating systems are operating. Also, many booked rooms remain unoccupied for long periods of time, approx. 60-65% of the day, while air-condition/heating systems are left running or kept in stand-by mode. Thus, energy within a hotel room is frequently consumed 24h a day, yearround regardless of whether or not the room is occupied.

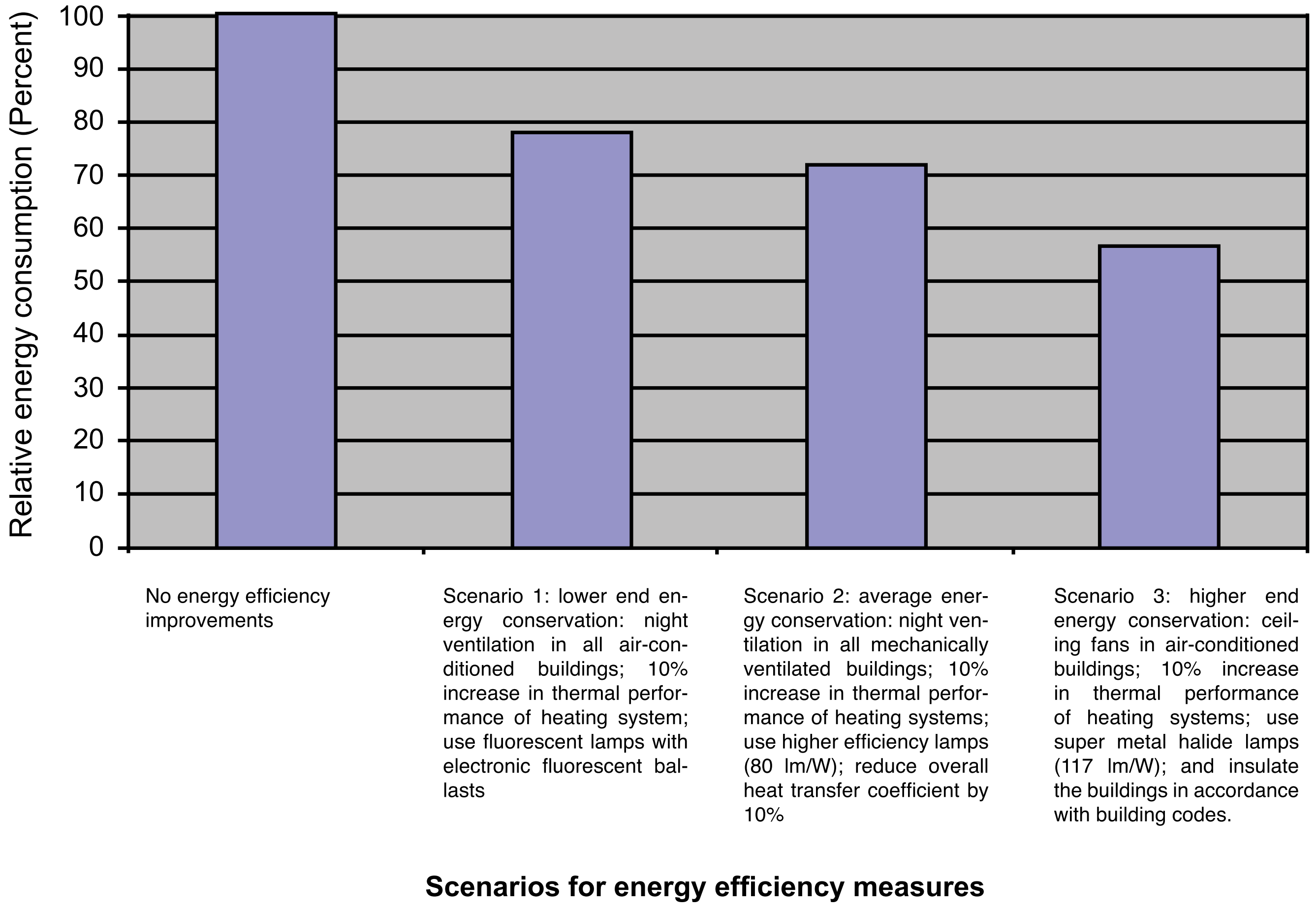


Figure 117: Energy efficiency savings potential estimated for hotels in Greece under low, average and high scenarios for energy efficiency measures (Source: Santamouris et al., 1996)

Various studies have estimated that hotels have the potential to save at least 10-15% of the energy they consume, depending on the age and size of the hotel, the type of equipment installed and the maintenance and operating procedures in use. An assessment of potential energy conservation in southern European hotels revealed that there is a potential for 25-30% energy savings, especially in hotels with constant energy consumption yearlong. European studies have estimated savings of 15-20% for heating, 5-30% for cooling, 40-70% for hot water and 7-60% for lighting (figure 117).

For new hotels, energy efficiency starts with the architecture including the aspects of natural ventilation, shading of windows and building materials (e.g. windows, insulation). In fact, energy efficient technologies and state-of-the art equipment should be included, from the very beginning. For existing hotels it is more difficult to influence the building design and structure. Exchange of technologies can help to reduce the energy demand, but also awareness rising regarding energy conservation/waster reduction targeted to the staff and guests helps to lower the energy consumption.

The following section provides some recommendation on how to lower waste of energy independent from implementation of a solar system, but important before considering to operate on renewable energy.

EFFICIENT LIGHTING

Modern lighting technology can help to reduce the energy demand for lighting up to 80% with short pay-back periods. The quantity of lamps used should also be revised. In hotels very often reams of lamps can be identified, which are not necessary to ensure the expected brightness nor would a reduction of the number of lamps be visible. Modern LED technology offers dimming and smart control functions and should be a must for any hotel, in order to drastically lower the energy consumption for lighting. Further, brightness and presence control should be integrated, whenever the operation is outside the control of the hotel management (e.g. rooms). Timers in combination with presence control are a useful tool for areas, such as corridors and rooms with low usage.

For details on lighting, please refer to chapter 3, section 1.1.

WATER SAVING TECHNOLOGIES

Saving water is important. Every litre of water that does not need to be heated reduces the energy consumption and directly influences the size of the solar system. Applications such as water saving showerheads are one of the first steps to implement. Today, the different showerheads have a water flow in a range of 3-20 l/min. With equal water pressure, many litres of water can be saved when replacing the showerhead with one of a lower water flow. The impact of an exchange is significant.

EXAMPLE 17 (SIMPLIFIED)

Efficient showerheads

Hotel with 1.000 Guests and an average showering time of 10 min:

Water temperature in shower: 37°C

Cold Water temperature: 25°C

Existing showerheads: 15 l/min

New water saving showerheads: 5 l/min

Water savings:10 l/min×10min×1,000 guests = 100,000 l/day

Energy savings: 100,000 litres equal 100,000 kg Q = 100,000 kg x 4,18 kWs/kgK × 12 K × 1/3,600 s/h = 1,393 kWh/day
→ **139 litres of diesel saved per day**

Additional to water saving showerheads, automatic mixing valves can be used to limit the temperature of the shower to e.g. 40°C (figure 118). By setting a maximum temperature, no water is wasted when adjusting for the preferred temperature level. It is also a useful device to reduce the risk of injury, due to extreme hot water in the bathroom facilities.

Figure 118: Automatic mixing valve

EFFICIENT BOILERS

Efficient boilers and hot water storage tanks do not influence the sizing of solar systems significantly. Boilers and DHW tanks do not influence the demand but the fuel consumption. It is therefore important to check the efficiency level of the boilers to reduce the fuel consumption for the same energy output.

EXAMPLE 17 (SIMPLIFIED)

Efficient Boilers

Hot water demand of 100 m^3/day

Hot water temperature: 50°C

Cold water temperature: 25°C

Energy demand: 100,000kg×4.18kWs/ kg K×25K×1/3,600s/h = 2,903 kWh/day

Old Boiler with efficiency of 65%: Fuel demand = 2,903kWh/0.65 = 4,466kWh equal to 447 litres of diesel

New Boiler with efficiency of 85%:Fuel demand = 2,903kWh/0.85 = 3,415kWh equal to 342 litres of diesel

Savings: 105 litres of diesel saved per day

COMBINED HEAT AND POWER GENERATION

As described in chapter 2, combined heat and power generation can help to improve the overall efficiency of the power and heat generation.

INSULATION OF PIPING AND STORAGE TANKS

Heat losses through pipelines and storage tanks can reach 20% of the total energy consumption, given that the pipelines and storage tanks are not well insulated nor protected from the sun. Simple tools, such as infrared or laser temperature measurement available for less than 100EUR, are helpful to check on thermal leakages and insulation (picture 94).

EFFICIENT AIR CONDITIONING

Regarding air-conditioning, it is not always necessary to invest in expensive and modern technology. It already helps, if the units are treated and maintained well. The level of the liquids and the ambient temperature on the outside re-cooling units influence the efficiency remarkably. Regular inspections and maintenance are mandatory. Shading elements to cover re-cooling units with efficient ventilation help to reduce the power consumption.

Moreover, awareness rising for guests regarding energy conservation, presence control and limitations on room temperatures can be added for further optimization. Sun protection by shutters or shading elements at the windows are also useful and can be added even in an existing hotel. Natural ventilation concepts to support the cooling systems, through higher airflow rates during night time to cool down the building structure can be implemented.

Figure 118: Temperature measuring device

All the measures above are not directly linked with the usage of solar energy in the hotels, but can help to reduce the demand first, which should always have the highest priority.
A reduction of the energy consumption helps to size the solar systems smaller, keep the investment lower and pay-back times shorter. Renewables can provide free and environmental friendly energy, but efficient energy consumption should be the first step into a more sustainable and cost-effective power consumption of a hotel.

04

SOLAR POWER IN DETAIL

Chapter Four

The following sections elaborate in detail on the technology of solar power, the basic components, requirements and design steps.

Independent small units are standard products and therefore not included in this chapter. Their design is simply based on required light intensities for solar streetlights or flow rates and pump heads for water pumps. Their concepts do not significantly differ from conventional products. The solar part itself is an integral part of the product and the customer can limit his/her focus on quality aspects, warranty and the reputation of the supplier and distributor. The datasheets and manufacturer support deliver sufficient information for the system design.

The components and requirements for solar power systems follow the guidelines of European standards at different climate conditions, as data of over 20 years is available. Some special requirements have been added, due to the special weather conditions in the MENA-region.

The exact solar irradiation is only secondary for the system design, such as grid-connected, self-consumption systems without batteries, net-metering applications or small supportive solar systems. Their design steps are similar and mainly based on expected solar yields. However, for battery and off-grid systems, it is absolutely necessary to design the solar solution on the accurate demand profile. Only measured or calculated data on the load profile can ensure accurate sizing and satisfying operations of the systems, whilst keeping the system costs optimal.

4.1 DESIGN AND SIZING OF SOLAR POWER FOR HOTELS

Regardless of the system type or size, some essential steps within the design have to be followed:

1. Check power demand
2. Check available areas for installation
3. Check location and voltage level for AC connection
4. Type and size of modules
5. Choice of inverters
6. String design
7. Design of support structure
8. Wiring and accessories
9. Check lightning protection
10. Simulation and shading analysis

For systems with batteries or hybrid systems with generators, additional steps and a detailed analysis of demand profiles are necessary to ensure accurate sizing and operations of the system.

Month	H GH	H CH	H BN	Ta
	(KWh/m^2)	(KWh/m^2)	(KWh/m^2)	(C)
Jan	190	38	263	14.1
Feb	188	40	231	15.2
Mar	230	50	255	16.6
Apr	238	46	258	17.3
May	231	57	242	17.9
Jun	200	66	187	17.9
Jul	185	77	147	16.6
Aug	181	81	134	16.4
Sep	184	69	161	16.0
Oct	197	55	207	15.2
Nov	186	47	218	14.3
Dec	184	38	243	13.5
Year	2396	665	2545	15.9

Legends

- H Gh: Imadiation of gbbal radiation horizontal
- H Dh: Imadiation of difuse radiation horizontal
- H Bn: Imadiation of beem
- Ta: Air temperatur

4.1.1 BASIC DATA FOR SIZING

The basic data for sizing a solar system include the information on the location of the project, climate data, available areas for installation and the demand of the project as well as basic information about a possible connection points to the grid, regardless of feed-in tariff agreements.

Climate data
Climate data serve as the basis for simulations of a solar power system using professional software, e.g. PV-Sol.

Climate data is usually found at sources such as Meteonorm or NASA and include all relevant data that are important for the sizing of a solar power system based on satellite data or data collected by weather stations in the area.

Climate data include:

- Global irradiation with fraction of diffuse and direct irradiation
- Wind speed
- Humidity
- Air temperature
- Rainfall

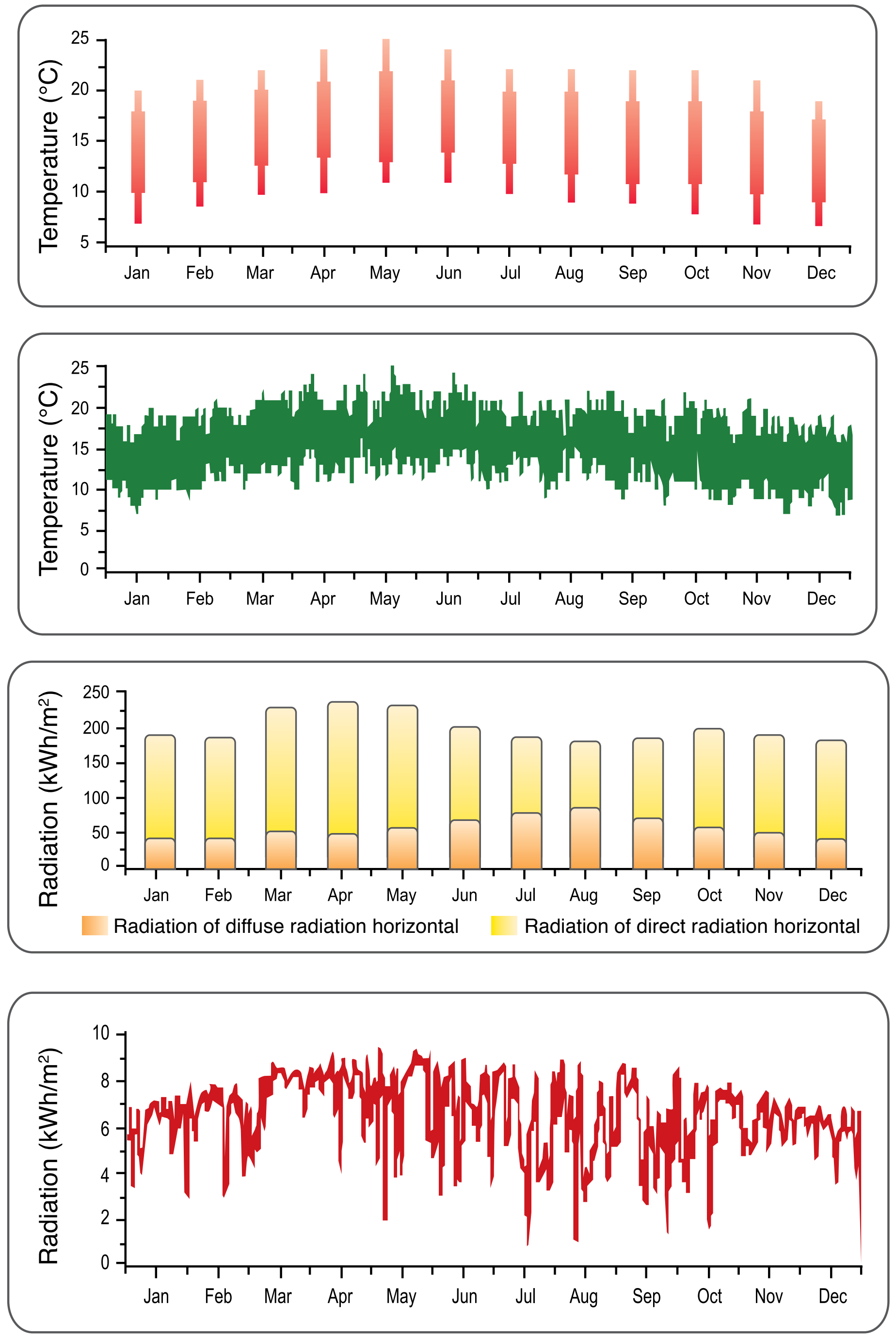
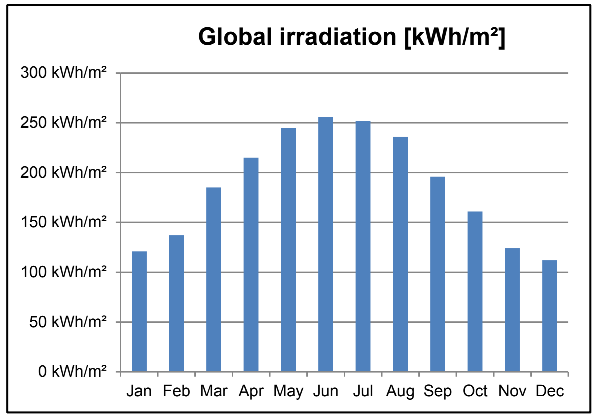


Figure 119: Climate data for Mekele Ethiopia (Source: Meteonorm)

Solar irradiation per year in Sharm el-Sheikh



Global irradiation [kWh/m²] *	
Jan	121 kWh/m²
Feb	137 kWh/m²
Mar	185 kWh/m²
Apr	215 kWh/m²
May	245 kWh/m²
Jun	256 kWh/m²
Jul	252 kWh/m²
Aug	236 kWh/m²
Sep	196 kWh/m²
Oct	161 kWh/m²
Nov	124 kWh/m²
Dec	112 kWh/m²
Total:	**2,240 kWh/m²**

Collector area, to provide 1 m³ water at 60 °C per day: **	11.7 m²
Energy savings per 1 m² collector area upto: ***	1,301 kWh/m²a

* Weather data from Meteonorm 6.1
** Based on max. per day; collector area is gross area; cold water 25 °C
*** Based on average per day with an efficiency of existing system of 70 % (boiler, tank & circulation losses)

Solar irradiation in Sharm el-Sheikh
© Aschoff Solar 2014

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Figure 120: Global irradiation in Sharm El Sheikh

For simulation purposes, the data is included in files to be used by any other software. For the draft design, some basic data, such as global irradiation per year, maximum and average irradiation per day can also be used to check different size options.

In the appendix an overview table including data on achievable solar yields per year for different locations in the MENA-region is given. The values in kWh/kWp per year are used to roughly draft a solar power system design, however it does not replace the need for accurate simulation based on actual project conditions.

For battery and hybrid systems it is essential to receive the daily profile of the location's climate data and to merge them with the daily demand profile. It is important to consider the different climate conditions at each season when designing the system. In the MENA-region however, the solar irradiation does not differ as strongly as in Europe, but other weather conditions such as sandy windstorms have to be taken into account during the design phase.

Power demand data

The minimum data needed for the design of solar power systems, that are not battery or hybrid system, is the monthly power demand for at least 12 months, based on measured data or billing from the utility. For new projects, the estimated demand for power has to be calculated based on the consumers in the hotel and the expected operating time in combination with the expected occupancy rate in each season. If available it is also beneficial to incorporate the fixed power demand, which has to be supplied independently from the occupancy rate.

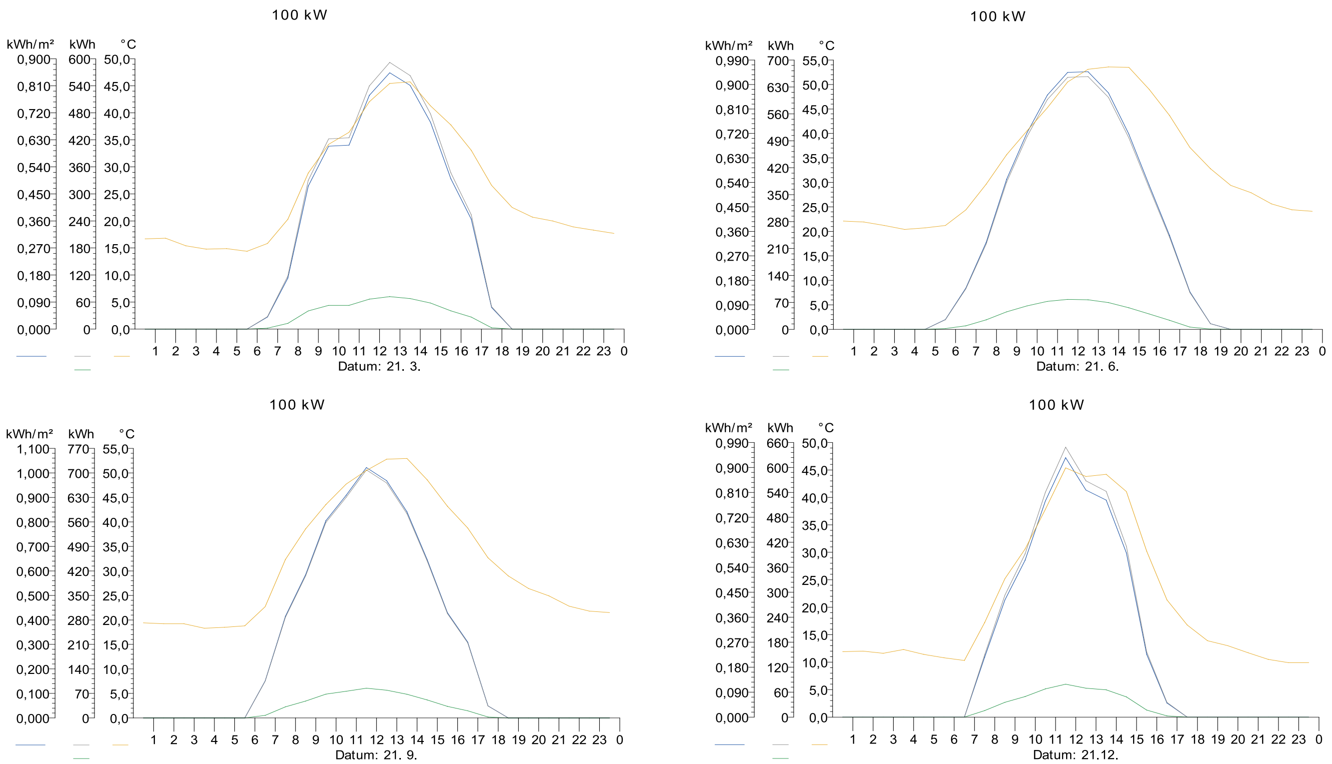

Figure 121: Daily profile of climate data in Cairo at different seasons

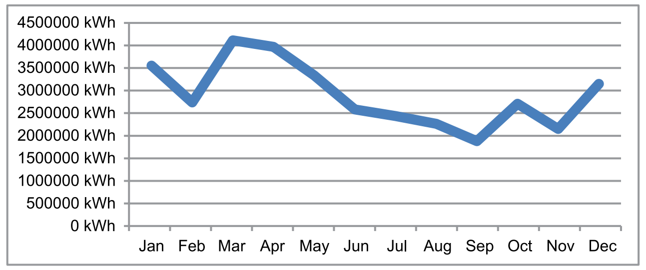

Figure 122: Yearly electricity demand profile of a hotel in El Gouna, Egypt (7000 rooms)

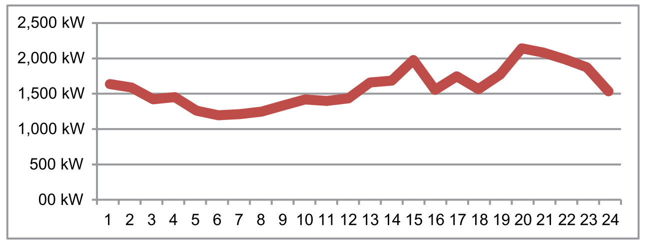

Figure 123: Daily power demand profile of a hotel in Marsa Alam, Egypt (in summer)

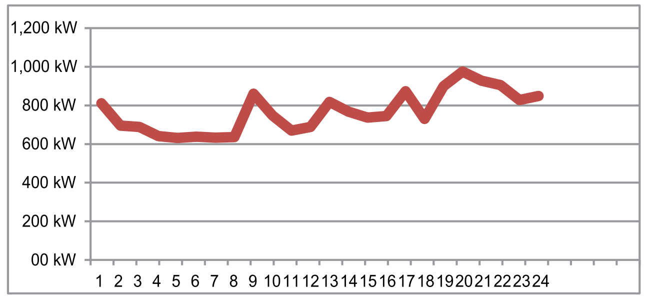

Figure 124: Daily power demand profile of a hotel in Marsa Alam, Egypt (in winter)

The more detailed the demand data, the more accurate and cost-efficient is the system. Unnecessary oversizing can be reduced to a minimal, further positively influencing the lifetime of the system. In existing hotels, it is strongly recommended to first install a suitable metering and monitoring system for a minimum of 6-12 months to record accurate data, in case they are not available. Another option is to install a small solar power application at just 10% of the estimated load and including a suitable metering system, which provides the needed data for further solar expansions. Saving just 1kW in needed solar power by including a metering system already pays off, as the system savings outweigh the costs of a metering system.

Data about location
Every solar project is special, as every site, hotel and roof is different. Building and roof drawings, or at least visualizations from Google Earth are necessary to get an idea about the possible areas for installations and needed distances for wiring. Information about the roof structure and available space is helpful, when choosing the possible support structure as well as to observe any limitations and shading effects.

have to be identified. A single line diagram of the whole hotel system can assist the connection of the solar system to the grid.

Lastly, it is central to collect weather and climate condition data and any other information, which could affect the system, based on experiences with other equipment installed in the hotel or other projects within this region. For instance, information on the influence of high saline air or water at coastal areas, special seasonal wind conditions or sandstorms are useful to prepare the system accordingly.

To construct a draft of the solar system size, various principles apply. The size depends on the budget, target and special situation of the project. The following approaches assist in drafting the size of a system, but do not replace an accurate design and should therefore only be used for the initial feasibility study and cost-efficiency of the potential project. In all cases, the size has to be rechecked with the capacity of the grid connection and the demand profile to confirm the feasibility study and to adhere to additional necessary control or safety features.

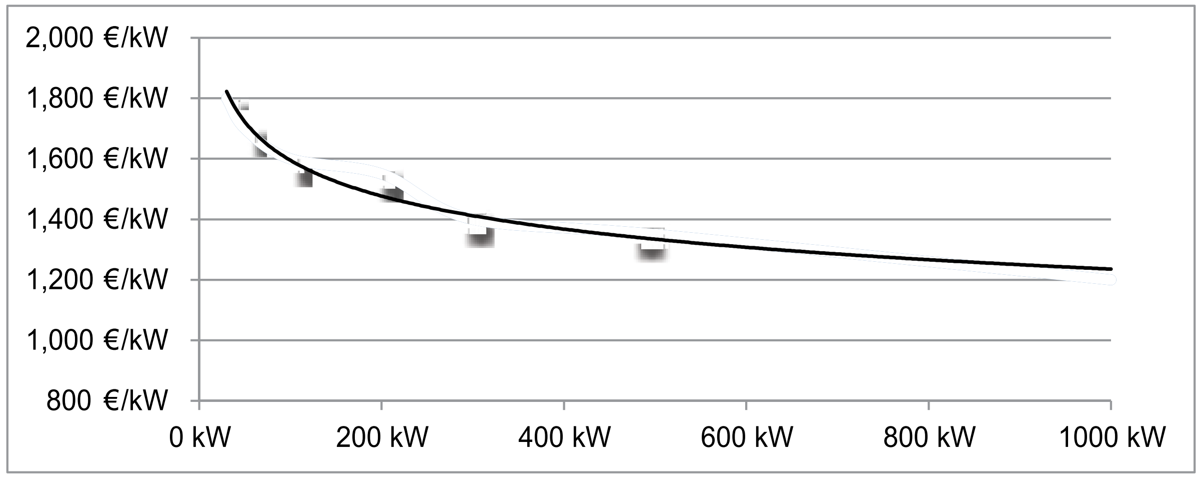

Figure 125: Specific system costs for rooftop installations without batteries

4.1.2 PRINCIPLES OF SIZING

Any accessible connections from the hotel to the grid should be identified with their maximum capacity in ampere or kVA, grid configuration, voltage and frequency level including their location within the hotel area. Further, substations of the public grid can also serve as connection points for the main distribution boards (MDB), main supply boards (MSB) or sub-boards of sufficient capacity within the area. Based on the final capacity of the solar system it has to be checked if the connection to the grid is suitable for the project or if other possibilities.

a) Sizing based on the budget
Sizing based on the budget is applicable for grid-connected, feed-in systems and self-consumption systems that are either intended for net-metering or are of relatively small size.

Approach:
The sizing of the solar system is depicted based on a fixed budget and the calculation of achievable savings according to the specific solar yield of the project's location. After the design, the system size has to be rechecked according to the available and suitable space and capacity of grid connections at the project's location.

EXAMPLE 19
Solar system sizing designed based on budget

System design for a hotel:

Budget: 150,000 EUR
System type: Self-consumption without batteries
Price of solar system: 1,500 EUR/kWp
Achievable solar yield[1]: 1,815 kWh/kWp
System size: 150,000 EUR / 1,500 EUR/kWP = 100 kW
Savings on electricity: 181,500 kWh/year (in first year of operation)
Base load of the hotel: 600kW
Space requirement: 100 kWp × 15 m²/kWp = 1.500m2
Available Space: 2.000 m²

The cost calculations should always include:

- Total investment
- Operational costs (0.2% of investment per year)
- Savings on electricity costs for self-consumption systems without batteries
- Feed-in compensation (if applicable)
- Savings on electricity costs
- Net-metering compensation (if applicable)
- Degradation according to datasheet of modules (e.g. 0.8% per year, if 20% output guaranteed after 25 years)
- Actual energy price and assumed energy price increase for self-consumption systems and net-metering systems

Project Amortization for Solar Power System

Project:	**Sizing based on Budget**	**Location:**	Luxor, Egypt		
System type:	Self-Consumption	**degradation**	0,80 % p.a.		
System Power	**100 kW**	**specific solar yield:**	1815 kWh/kWp p.a.	**operational costs:**	0,2 % of invest
Energy price:	0,07 EUR/kWh	**increase energy price:**	20% p.a.	**investment:**	150.000,00 €

year of operation	1	2	3	4	5	6	7	8	9	10
solar yield kWh/a	181.500	180.048	178.608	177.179	175.761	174.355	172.960	171.577	170.204	168.842
accumulated solar energy kWh	181.500	361.548	540.156	717.334	893.096	1.067.451	1.240.411	1.411.988	1.582.192	1.751.035
energy price in EUR/kWh	0,07	0,08	0,10	0,12	0,15	0,17	0,21	0,25	0,30	0,36
fed in compensation in EUR	12.705	15.124	18.004	21.432	25.512	30.370	36.152	43.035	51.229	60.983
operational costs in EUR	300	300	300	300	300	300	300	300	300	300
accumulated earnings in EUR	12.405	27.229	44.933	66.064	91.276	121.346	157.198	199.933	250.863	311.546
account balance in EUR	-137.595	-122.771	-105.067	-83.936	-58.724	-28.654	7.198	49.933	100.863	161.546

year of operation	11	12	13	14	15	16	17	18	19	20
solar yield kWh/a	167.492	166.152	164.823	163.504	162.196	160.898	159.611	158.334	157.068	155.811
accumulated solar energy kWh	1.918.526	2.084.678	2.249.501	2.413.005	2.575.201	2.736.099	2.895.710	3.054.045	3.211.112	3.366.923
energy price in EUR/kWh	0,43	0,52	0,62	0,75	0,90	1,08	1,29	1,55	1,86	2,24
fed in compensation in EUR	72.595	86.417	102.870	122.457	145.772	173.528	206.567	245.898	292.716	348.450
operational costs in EUR	300	300	300	300	300	300	300	300	300	300
accumulated earnings in EUR	383.840	469.957	572.527	694.684	840.156	1.013.684	1.220.251	1.466.149	1.758.865	2.107.315
account balance in EUR	233.840	319.957	422.527	544.684	690.156	863.684	1.070.251	1.316.149	1.608.865	1.957.315

Figure 126: Amortization plan of a solar power system designed based on budget

[1] A global solar yield list is provided in the appendix

b) Sizing according to available space for installation

Sizing based on the available space is applicable for grid-connected, feed-in systems and self-consumption systems of a small size or with net-metering option

Approach:

The sizing of the solar system is based on the available roof or free field area. Possible areas can include car-ports, building roofs, shading elements on terraces or any other space available, which can be covered with solar panels at a feasible inclination, orientation and without shading effects. After the design step, the system size has to be rechecked regarding the demand and capacity of the grid connections as well as regarding cost calculation for the project. For a pitch roof the necessary space for 1kW solar energy installed is approx. 7m², including walkways for maintenance. Due to the shading effect, flat roof and ground installations require twice the size between 12-15m², depending on the inclination and shading distance.

EXAMPLE 20

Solar system sizing based on available space
System design for a hotel:

Location:	Luxor, Egypt
Available space on a flat roof:	1,000 m²
Possible solar power system:	1,000 m² / 15 = 67 kW
Base load of the hotel:	600 kW
System type:	Self-consumption without batteries
Price of solar system:	1,700 EUR/kWp
Achievable solar yield:	1,815 kWh/kWp
System costs:	67 kW×1,700 EUR/kWP = 113,900 €
Max. budget:	200,000 €
Savings on electricity:	181,500 kWh/year (in first year of operation)

The cost calculations should always include:

- Total investment
- Operational costs (0.2% of investment per year)
- Savings on electricity costs for self-consumption systems without batteries
- Feed-in compensation (if applicable)
- Savings on electricity costs
- Net-metering compensation (if applicable)
- Degradation according to datasheet of modules (e.g. 0.8% per year, if 20% output guaranteed after 25 years
- Actual energy price and assumed energy price increase for self-consumption systems and net-metering systems

aschoff solar

Project Amortization for Solar Power System

Project: Sizing based on Space **Location:** Luxor, Egypt
System type: Self-Consumption **degradation** 0,80 % p.a.
System Power 67 kW **specific solar yield:** 1815 kWh/kWp p.a. **operational costs:** 0,2 % of invest
Energy price: 0,07 EUR/kWh **increase energy price:** 20% p.a. **investment:** 113.900,00 €

year of operation	1	2	3	4	5	6	7	8	9	10
solar yield kWh/a	121.605	120.632	119.667	118.710	117.760	116.818	115.883	114.956	114.037	113.124
accumulated solar energy kWh	121.605	242.237	361.904	480.614	598.374	715.192	831.076	946.032	1.060.069	1.173.193
energy price in EUR/kWh	0,07	0,08	0,10	0,12	0,15	0,17	0,21	0,25	0,30	0,36
fed in compensation in EUR	8.512	10.133	12.062	14.359	17.093	20.348	24.222	28.834	34.324	40.859
operational costs in EUR	228	228	228	228	228	228	228	228	228	228
accumulated earnings in EUR	8.285	18.190	30.024	44.156	61.021	81.141	105.135	133.741	167.837	208.468
account balance in EUR	-105.615	-95.710	-83.876	-69.744	-52.879	-32.759	-8.765	19.841	53.937	94.568

year of operation	11	12	13	14	15	16	17	18	19	20
solar yield kWh/a	112.219	111.322	110.431	109.548	108.671	107.802	106.940	106.084	105.235	104.393
accumulated solar energy kWh	1.285.413	1.396.734	1.507.165	1.616.713	1.725.384	1.833.186	1.940.126	2.046.210	2.151.445	2.255.839
energy price in EUR/kWh	0,43	0,52	0,62	0,75	0,90	1,08	1,29	1,55	1,86	2,24
fed in compensation in EUR	48.638	57.899	68.923	82.046	97.668	116.263	138.400	164.751	196.120	233.461
operational costs in EUR	228	228	228	228	228	228	228	228	228	228
accumulated earnings in EUR	256.878	314.549	383.245	465.063	562.503	678.766	817.166	981.918	1.178.038	1.411.499
account balance in EUR	142.978	200.649	269.345	351.163	448.603	564.866	703.266	868.018	1.064.138	1.297.599

Figure 128: Amortization plan of a solar power system designed based on available space

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Project Amortization for Solar Power System

Project: Sizing based on Space **Location:** Luxor, Egypt
System type: Self-Consumption **degradation** 0,80 % p.a.
System Power 67 kW **specific solar yield:** 1815 kWh/kWp p.a. **operational costs:** 0,2 % of invest
Energy price: 0,07 EUR/kWh **increase energy price:** 20% p.a. **investment:** 113.900,00 €

year of operation	1	2	3	4	5	6	7	8	9	10
solar yield kWh/a	121.605	120.632	119.667	118.710	117.760	116.818	115.883	114.956	114.037	113.124
accumulated solar energy kWh	121.605	242.237	361.904	480.614	598.374	715.192	831.076	946.032	1.060.069	1.173.193
energy price in EUR/kWh	0,07	0,08	0,10	0,12	0,15	0,17	0,21	0,25	0,30	0,36
fed in compensation in EUR	8.512	10.133	12.062	14.359	17.093	20.348	24.222	28.834	34.324	40.859
operational costs in EUR	228	228	228	228	228	228	228	228	228	228
accumulated earnings in EUR	8.285	18.190	30.024	44.156	61.021	81.141	105.135	133.741	167.837	208.468
account balance in EUR	-105.615	-95.710	-83.876	-69.744	-52.879	-32.759	-8.765	19.841	53.937	94.568

year of operation	11	12	13	14	15	16	17	18	19	20
solar yield kWh/a	112.219	111.322	110.431	109.548	108.671	107.802	106.940	106.084	105.235	104.393
accumulated solar energy kWh	1.285.413	1.396.734	1.507.165	1.616.713	1.725.384	1.833.186	1.940.126	2.046.210	2.151.445	2.255.839
energy price in EUR/kWh	0,43	0,52	0,62	0,75	0,90	1,08	1,29	1,55	1,86	2,24
fed in compensation in EUR	48.638	57.899	68.923	82.046	97.668	116.263	138.400	164.751	196.120	233.461
operational costs in EUR	228	228	228	228	228	228	228	228	228	228
accumulated earnings in EUR	256.878	314.549	383.245	465.063	562.503	678.766	817.166	981.918	1.178.038	1.411.499
account balance in EUR	142.978	200.649	269.345	351.163	448.603	564.866	703.266	868.018	1.064.138	1.297.599

Figure 129: Amortization plan of a solar power system designed based on targeted savings

c) Sizing based on targeted savings

Sizing based on targeted savings is applicable for self-consumption systems with or without batteries and fuel saver solutions. Hotels who want to follow certain company policies to reduce the energy consumption or to be accredited certain energy efficiency Standard (e.g. LEED[3]) can implement a solar system mainly on the maximum energy savings possible.

Approach:
The sizing of the solar system based on maximum energy savings is possible if the budget and available space are flexible. After the design step, the system size has to be rechecked with the available space, the budget and the demand profile to check if the solar fraction exceeds the demand profile, leading to solar excess, in which it has to be either stored or the system size reduced.

EXAMPLE 21

Solar system size based on maximum energy savings

Solar design for a hotel:

Location:	Luxor, Egypt
Total energy consumption:	1,000,000 kWh/year
Targeted savings:	10%
Required solar yield:	100,000 kWh/year
Achievable solar yield:	1,815 kWh/kWp
Required system size:	100,000 kWh / 1,815 kWh/kWp = 55 kWp
Space requirement:	15 m²/kWp × 55 kWp = 825 m²

Available Space on a flat roof:	1,000 m² ✓
Base load of the hotel:	120 kW ✓
System type:	Self-consumption without batteries
Price of solar system:	1,700 EUR/kWp
System costs:	55 kW×1,700 EUR/kWP = 93,500 €
Maximum budget:	100,000 € ✓

The cost calculations should always include:

- Total investment
- Operational costs (0.2% of investment per year)
- Savings on electricity costs for self-consumption systems without batteries
- Feed-in compensation (if applicable)
- Savings on electricity costs
- Net-metering compensation (if applicable)
- Degradation according to datasheet of modules (e.g. 0.8% per year, if 20% output guaranteed after 25 years)
- Actual energy price and assumed energy price increase for self-consumption systems and net-metering systems

[3]LEED stands for Leadership in Energy and Environmental Design. A sustainability rating system for buildings by the United States Green Building Council (USGBC). sustainable design.

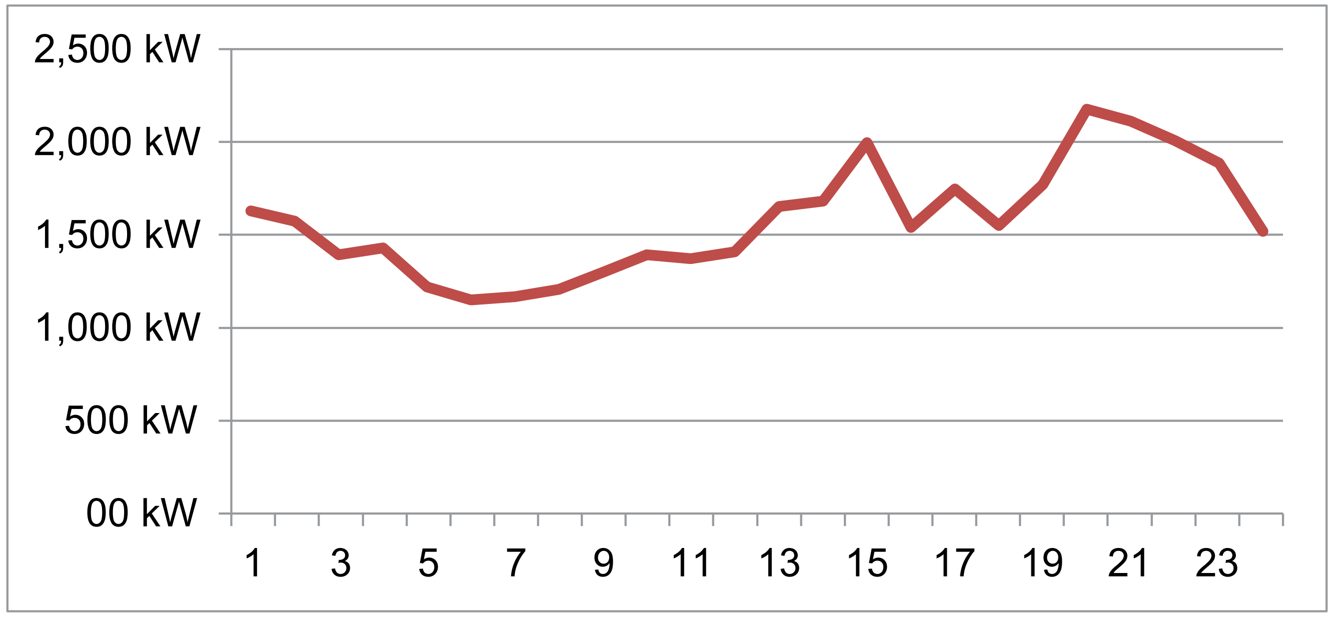


Figure 130: Load profile and solar yield with storage into batteries

d) Sizing based on daily and seasonal power demand profile

Sizing based on seasonal power demand profile is applicable for self-consumption systems with or without batteries, stand-alone systems with batteries, hybrid systems with switch operation and fuel saver solutions. For off-grid solutions in particular, the sizing of the system has to map the seasonal power demand profile, to provide sufficient energy in peak seasons.

Approach:

The sizing of the solar system is based on the daily and seasonal demand profile. In order to size accurately, data on the energy consumption of each season has to be available. The more detailed the data, the more accurate the system size and therefore the less oversizing is needed. The result is a more cost-efficient solar application. After the design step, the system size has to be rechecked on available space and budget.

EXAMPLE 21

Solar system size based on seasonal power demand
Solar system design for a hotel:

Location:Luxor, Egypt Average daily load profile (in summer)

BaseLoad: 550 kW

Daily Demand: 18,000 kWh

Average solar yield: 5.0 kWh/kWp per day

System size based on demand: 18,000 kWh ⁄ 5.0 kWh/kWp = 3,600 kWp (In this case batteries have to be included or net-metering policy should be applied)

Space requirement: 15 m^2/kWp × 360 kWp = 54,000 m^2

Available Space on field: 10,000m^2 (CAUTION: Not enough space available!)

Maximum System size: 10,000 m^2 / 15 m^2/kWp = 667 kWp

System type: Self-consumption system with batteries

Price of solar system: 1,750 EUR/kWp

System costs: 667 kW×1,750 EUR/kWP =1,167.250 €
Max. budget:1,500,000 € ✓

System size based on fixed demand:	550 kW
No solar exceeds and no battery necessary	
Achievable solar fraction:	550kWp×5kWh/kWp = 2,750kWh/day
→ Solar fraction =	2,750 ⁄ 18,000 = 15%
Space requirement:	15m2/kWp×550kWp = 8,250m2
Available space on field:	10,000m2 ✓
System type:	Self-consumption without batteries
Price of solar system:	1,350EUR/kWp
System costs:	550kW×1,350EUR/kWP = 742,500€
Max. budget:	1,000,000€ ✓

Project Amortization for Solar Power System

Project:	**Sizing based on demand**	**Location:** Luxor, Egypt			
System type:	Self-Consumption	**degradation**	0,80 % p.a.		
System Power	**550 kW**	**specific solar yield:**	1815 kWh/kWp p.a.	**operational costs:**	0,2 % of invest
Energy price:	0,07 EUR/kWh	**increase energy price:**	20% p.a.	**investment:**	742.500,00 €

year of operation	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
solar yield kWh/a	998.250	990.264	982.342	974.483	966.687	958.954	951.282	943.672	936.123	928.634
accumulated solar energy kWh	998.250	1.988.514	2.970.856	3.945.339	4.912.026	5.870.980	6.822.262	7.765.934	8.702.057	9.630.690
energy price in EUR/kWh	0,07	0,08	0,10	0,12	0,15	0,17	0,21	0,25	0,30	0,36
savings in EUR	69.878	83.182	99.020	117.873	140.317	167.033	198.836	236.694	281.761	335.408
operational costs in EUR	1.485	1.485	1.485	1.485	1.485	1.485	1.485	1.485	1.485	1.485
accumulated savings in EUR	68.393	150.090	247.625	364.013	502.845	668.393	865.744	1.100.953	1.381.229	1.715.152
account balance in EUR	-674.108	-592.410	-494.875	-378.487	-239.655	-74.107	123.244	358.453	638.729	972.652

year of operation	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
solar yield kWh/a	921.204	913.835	906.524	899.272	892.078	884.941	877.862	870.839	863.872	856.961
accumulated solar energy kWh	10.551.895	11.465.730	12.372.254	13.271.526	14.163.603	15.048.545	15.926.406	16.797.245	17.661.117	18.518.078
energy price in EUR/kWh	0,43	0,52	0,62	0,75	0,90	1,08	1,29	1,55	1,86	2,24
savings in EUR	399.270	475.291	565.786	673.512	801.749	954.402	1.136.120	1.352.437	1.609.941	1.916.473
operational costs in EUR	1.485	1.485	1.485	1.485	1.485	1.485	1.485	1.485	1.485	1.485
accumulated savings in EUR	2.112.937	2.586.743	3.151.044	3.823.071	4.623.334	5.577.736	6.713.856	8.066.292	9.676.233	11.592.707
account balance in EUR	1.370.437	1.844.243	2.408.544	3.080.571	3.880.834	4.835.236	5.971.356	7.323.792	8.933.733	10.850.207

Figure 132: Amortization plan of a solar power system designed based on demand

The cost calculations should always include:

- Total investment
- Operational costs (0.2% of investment per year)
- Savings on electricity costs for self-consumption systems without batteries
- Feed-in compensation (if applicable)
- Savings on electricity costs
- Net-metering compensation (if applicable)
- Degradation according to datasheet of modules (e.g. 0.8% per year, if 20% output guaranteed after 25 years)
- Actual energy price and assumed energy price increase for self-consumption systems and net-metering systems

4.1.3 SOLAR SYSTEM DESIGN STEPS

Before starting to draft a detailed design of a solar system, a few basic decisions have to be made:

- Choice of system concept according to chapter 2, section 1
- Draft sizing of the system and recheck of size according to chapter 4, section 1.2.
- Prepare the areas for installation of the solar system

In addition, it is necessary to check and reconfirm the following:

- Ground analysis in case of an on-ground installation, with respect to possibility of a pile foundation
- Check load carrying capacity of the roof in case of a rooftop installation
- Check installation area for shading (e.g. trees, surrounding high buildings, etc.)
- Check regulations and requirements for a grid connection
- Check if feed-in tariff scheme and net-metering policies are applicable
- Recheck possible grid connection points regarding capacity and suitability
- Reconfirm demand profile
- Check grid parameters (e.g. voltage, frequency, grid configuration)

a) Agree on system concept and design data for components

The first step of the system design is to agree on the system concept and the basic design data of the main components:

- Nominal capacity of solar power system in Kwp
- Available space for installation
- Type of inverters required (e.g. standard grid-connected or island inverters)
- Battery capacity in kWh (if applicable)
- Generator capacity in kVA (if applicable)
- Connection point to the grid (if applicable)
- Possible locations for installing the components
- Necessary control and metering

Based on the concept requirements specifications, potential suppliers and system providers should generate an accurate and comprehensive proposal, including:

- Site information incl. layout drawing
- Google Earth view of the site
- Load calculation of the roof (if applicable)
- Ground analysis (if on-ground installation)
- Grid information
- Information on local conditions (e.g. weather) and regulations
- Required system concept
- Basic data on capacity and demand profile

b) Modules and inverters

Once the system concept is chosen, the second step is to decide on the type of modules best suitable for the project's size, climate, available space and budget. If enough space is available, it is possible to choose modules at a lower price per kWp that have a lower W output per panel and thus require more space. If space is limited, but capacity has to be reached, modules with higher panel efficiency are required at a higher cost.

EXAMPLE 22

Modules and inverters

Available space: 1,200 m²

Required capacity: 200 kWp

Module 1

Nominal capacity: 260 Wp

Dimensions: 1.65 m × 0.992 m = 1.63 m²
equal to 160 W/m2

Module 2

Nominal capacity: 290 Wp

Dimensions: 1.66 m×0.99 m=1.64 m² equal to 177 W/m²

Required module area:

Module 1:200,000 W ⁄ 160 W/m² = 1,250 m² – Not enough!

Module 1:200,000 W ⁄ 177 W/m² = 1,129 m² – Enough!

The module capacity is only one of many criteria to choose from. Also, module characteristics with respect to environmental conditions and operating temperature must be taken into account. For special installations on façades or in case of suboptimal orientation, different module technologies should be compared on the maximum solar yield. When preparing the available roof space prior installation, additional space for walkways and safety margins on the edges have to be calculated. Larger module areas must be separated into different parts with a gap for every 10-15m, to allow any thermal extensions without incurring high tension on the roof. For an accurate system design, obstacles on the roof, such as chimneys, air-conditioning units or satellites, including their shading effects must be taken into account. Once module area and type are chosen, a suitable inverter concept and type must be fixed.

Table 5: Space requirements per kWp for different modules

Module type	Efficiency of Module	Required space for 1 kWp
High efficiency cells (HIT)	17 – 20%	5 – 6 m²
Monoccrystalline	11 – 17%	6 – 9 m²
Polycrystalline	10 – 16%	6 – 10 m²
Thin-film CIS	7 – 14%	7 – 12,5 m²
Thin-film CdTe	7 – 13%	9 – 17 m²
Thin-film micromorph	7 – 12%	8,5 – 15 m²
Thin-film amorph	4 – 7%	15 – 26 m²

These different types of inverter concepts are available:

1. Central inverter for the complete system In case of a larger system, several centralized inverters can be used in conjunction (figure 134). The strings in the solar array are connected to the central inverter(s) via a string combiner box and main DC wires.

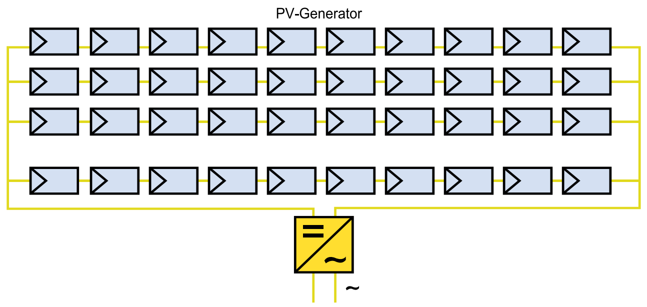


Figure 134: System concept with one central inverter

2. Larger solar power system with a capacity of several MW can also be realized with a Master-Slave concept (figure 135), in which the solar arrays are connected to a cluster of normally 3-4 inverters. In the lower irradiation range only the master inverter is operating. At times of higher irradiation, the additional inverters are added. To ensure equal load and operating time of all inverters, the master function is rotated to each inverter in the system. The advantage of the Master Slave is that especially at lower irradiation the system efficiency is higher String inverters for small to medium sized systems
3. For smaller and middle size systems, string inverters are the most popular solution (figure 136). The inverters have one or several string inputs, in which a certain number of modules are connected in series. In particular, for systems with different orientations or shading conditions, the string inverter solution allows a leaner design and higher system efficiency. It is important to connect only modules with identical conditions (e.g. orientation, shading) into one string. For string inverters, string combiner boxes and main DC wiring are usually not required, as the strings are directly connected to the inverters (picture 109). String inverters can be either single or 3-phase inverters.
4. Micro inverters for single modules If micro or module inverters are used, each module within the solar power system is permanently working on its individual maximum power point (figure 137). As a result, it is ensured that the system efficiency is at its highest, which is an advantage over other inverter options. When using micro inverters, several modules are connected in parallel to their individual inverters. It is important to pay attention to the current in the AC consumer grid, as the current increases to a high level and existing wiring and protection concepts have to be rechecked or aligned accordingly. Micro inverters are most suitable for smaller scale systems, especially if the system is split into several, very small units, such as installations on bungalows.

An experienced system provider or supplier should assist the decision for the most suitable concept. After the concept for inverters is chosen, the right type and quality of the inverters have to be fixed. System integrators or suppliers can support the decision based on the technical information of the manufacturers and the project conditions. Module and inverter have to be synchronized to ensure optimized operation. The AC capacity of the inverters should be around 10-20%.

c) Module arrangement and string design

The modules and strings have to be arranged based on the required solar output and inverter concept. The amount of strings and the number of modules per string have to be defined and connected to the available inputs of the inverters. Important for number of modules per string are the input voltage of the inverters and the module voltage under different conditions. As described before, all solar modules have fluctuating output voltages at changing temperatures, differing from the STC[6] characteristics.

As a basic rule for all modules, the higher the temperature, the lower the voltage. The inverters have a certain MPP DC input voltage range for their MPP inputs. Therefore, the MPP input range and the maximum DC input voltage of the inverter have to be checked at highest and lowest temperatures under operational conditions. To calculate and check the maximum input voltage when deciding on the amount of modules per string, 2 possible outcomes should be avoided:

1) The minimum number of modules per string with voltage under highest temperature

It must be ensured that the module voltage under lowest temperature conditions does not exceed the maximum input voltage of the inverter.

$N_{max} = VInv\ max / Voc\ module\ (low\ temp.)$
$Voc\ (low\ temp) = (1 - DT \times TCVoc / 100\%) \times Voc\ (STC)$

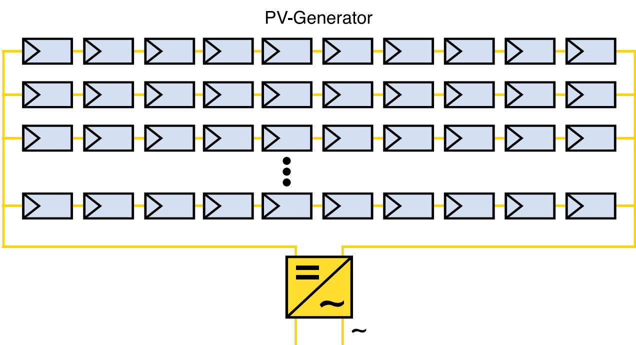


Figure 135: Central inverter on a field installation

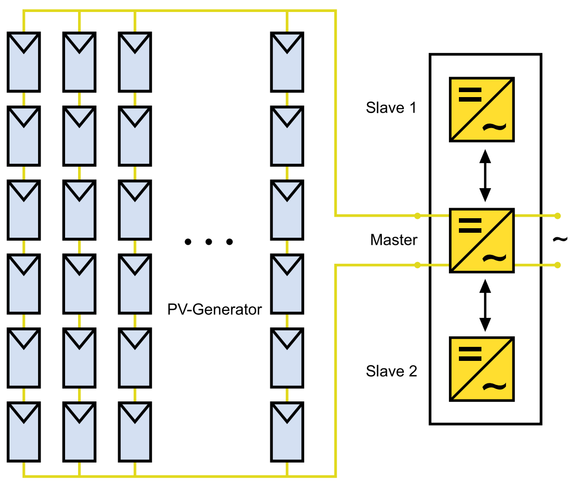


Figure 136: Central concept with Master-Slave

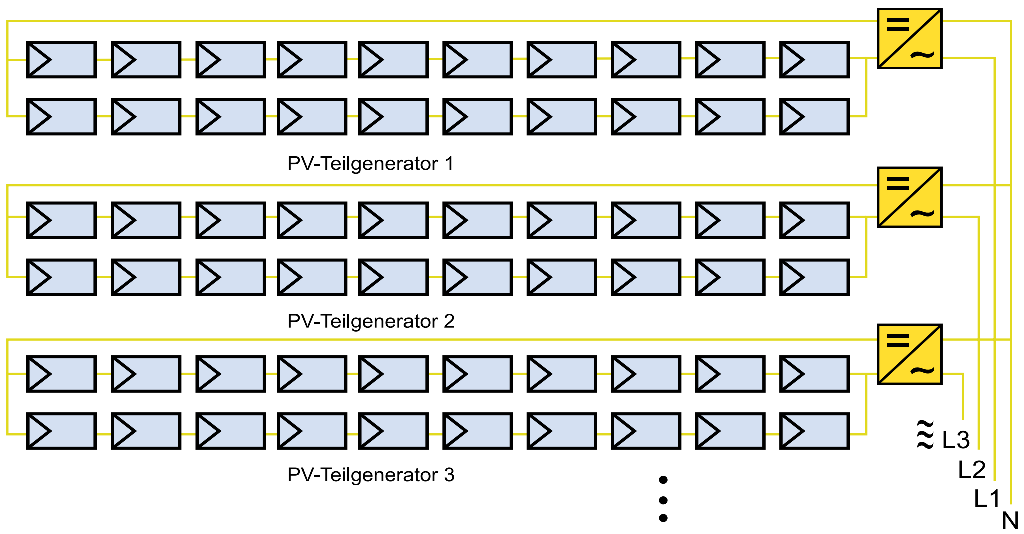


Figure 137: System concept with string inverters

[6] Standard Test Conditions

EXAMPLE 23
Module arrangement and string design

Inverter: SMA Tripower 15000

Max. DC input voltage

VInv max: 1000V

MPP input voltage range: 380V to 800V

Module: Solarworld Mono Black 285Wp (monocrystalline)

Open circuit voltage

Voc (STC): 39.7V

Thermal characteristic

TCVoc: -0.30%/°C (also called boc)

Temperature assumption: 20°C

Temperature difference to STC DT:-5°C

Figure 138: Typical string inverters with strings directly connected to the inverter

→ V_{oc} (20°C) = (1- DT×TCVoc / 100%)×Voc (STC)

→ V_{oc} (20°C) = (1 – 5°C×-0.30%/°C / 100%)×39.7V

→ V_{oc} (20°C) = 1.015×39.7 V = 40.3 V

N_{max} = 1000V/40.4 V = 24.8 modules

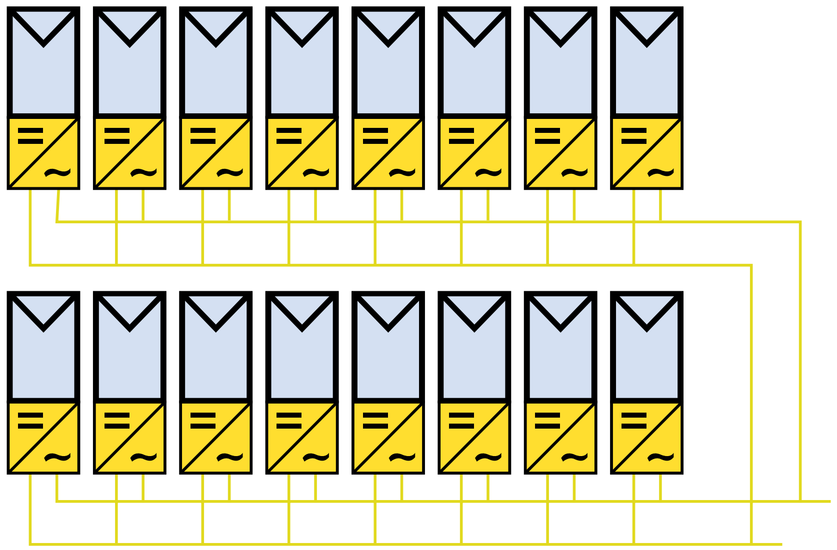


Figure 139: System concept with micro inverters

2) The maximum number of modules per string with voltage under lowest temperature

In the summer months, the module temperature can reach 70-80°C, especially in arid climates. To calculate the minimum voltage, the maximum assumption of module temperature should be used:

$N_{min} = VMpp(Inv\ min) / VMPP\ (Module\ high\ temp)$
$VMPP\ (high\ temp) = (1 + DT \times TCVMPP / 100\%) \times VMPP\ (STC)$

The MPP voltage of the module for temperatures deviating from the STC[6] is calculated with a factor bMPP. The bMPP can either be found in the datasheet of the modules or can be calculated via the characteristics for standard modules (table 3). If no data is available, the temperature coefficient for power (TCmpp) can be used for the calculation, instead of the TCVMPP for the draft design.

Table 6: Thermal characteristic for VMPP from Voc

Type of module	TCVMPP
Polycrystalline	TCVoc – 0.11 %/°C
Monocrystalline	TCVoc – 0.10 %/°C
Thin-film amorphous	TCVoc – 0.02 %/°C
Thin-film CIS	TCVoc – 0.05 %/°C
Thin-film CdTe	TCVoc – 0.01 %/°C

[2] Maximum Power Point

EXAMPLE 25

MPP Voltage

Inverter: SMA Tripower 15000

MPP input voltage range: 380V to 800V

Min. MPP input voltage: 380V

Module: Solarworld Mono Black 285Wp (Monocrystalline)

MPP voltage VMPP (STC): 31.3 V

Thermal characteristic

TCVoc:-0.30%/°C (also called boc)

TCVMPP:TCVoc – 0.10%/°C = -0.40 %/°C

Temperature assumption:80°C

Temperature difference to STC DT : 55°C

→ V_{MPP} (80°C) = (1 + DT×TCVoc / 100%)×Voc (STC)

→ V_{MPP} (80°C) = (1 + 55°C×-0.40%/°C / 100%)×31.3 V

→ Voc (20°C) = 0.78×31.3V = 24.4V

N_{min} = 380 V / 24,4 V = 15,6 modules

IMPORTANT: The strings design for this system should be based on 16-24 modules per string to ensure accurate operation.

Once the required quantity per string is verified, it is necessary to recheck, whether the maximum current from the solar power modules does not exceed the maximum input current of the inverter. The maximum number of strings connected to the inverter is calculated as follows:

Nstrings = Imax Inv / I max string

The current of a solar module changes with the irradiation according to the characteristics of the specific module. As a general rule for all module types, the higher the irradiation, the higher the current. To calculate the maximum power in a string, the modules' short circuit current under STC (1000W/m²) and a factor to represent higher irradiation than in the STC, are used.

I max string = Ioc x 1.25 (A)

Table 7: Example of a string design and inverter check based on SMA sunny design

6 x STP 25000TL-30 (PV system section 1)

Peak power:	150.30 kWp
Total number of PV modules:	560
Number of PV inverters:	6
Max. DC power (cos φ = 1):	25.55 kW
Max. AC active power (cos φ = 1):	25.00 kW
Grid voltage:	400V (230V / 400V)
Nominal power ratio:	91 %
Dimensioning factor:	110 %
Displacement power factor cos φ:	1

STP 25000TL-30

PV design data

Input A: PV array 1
60 x ZhiShine PV-tech Co. Ltd. ZXP6-60-255/P (10/2013), Azimuth angle: 90 °, Tilt angle: 15 °, Mounting type: Roof

Input B: PV array 2
50 x ZhiShine PV-tech Co. Ltd. ZXP6-60-255/P (10/2013), Azimuth angle: -90 °, Tilt angle: 15 °, Mounting type: Roof

	Input A	Input B
Number of strings	3	2
PV modules per string	20	25
Peak power (input)	15.30 kWp	12.75 kWp
Typical PV voltage	531 V	664 V
Min. PV voltage	501 V	626 V
Min. DC voltage (Grid voltage 230 V)	150 V	150 V
Max. PV voltage	775 V	968 V
Max. DC voltage	1000 V	1000 V
Max. current of PV array	25.2 A	16.8 A
Max. DC current	33 A	33 A

EXAMPLE 26

Maximum power in a string

Inverter: SMA Tripower 15000

Imax Inv: 33 A

Module: Solarworld Mono Black 285 Wp (Monocrystalline)

→ Isc (STC) = 9.84A
→ I max string = 1.25×9.84 A = 12.3 A

Nstrings = 33A / 12.3A = 2.7 strings

According to the basic string design, the following aspects have to be considered to ensure optimized string and inverter interactions:

- Ensure operations in the operating range of the inverters
- Ensure operations in the MPP range of the inverters
- In case of power peaks, minimize losses via automated power reduction
- Take shading into account
- Take high ambient temperatures into account
- These aspects should be included in the draft design of the solar system and are essential to be rechecked. However, a detailed design from standard software, such as PV-Sol or SMA sunny design, includes the calculation of the number of strings and their connection with different inverters.

The module arrangement and detailed string plan is organized based on the number of strings and the quantity of modules per string. The string plan consists of the module identification and connection of the module inputs to the inverters.

EXAMPLE 27

Inverter plan and wiring for a 35kW solar power system

d) Support structure design

The support structure of a solar power system has do be aligned to the module arrangements and planned installation location. Depending on the type of installation, the steps have to be followed:

1. Ground analysis for on-ground system installations
2. Load carrying capacity and type of roof plates for pitch roof installation
3. Load carrying capacity and roof surface for flat roof installations

In addition, the following information has to be given:

1. Module arrangement (e.g. location, inclination, orientation)
2. Type and size of modules
3. Site information (e.g. surrounding area, height of building)
4. Type of support structure

Qualified suppliers are using questionnaires for the different applications as seen in figure 142 for a roof parallel and pitch roof installation.

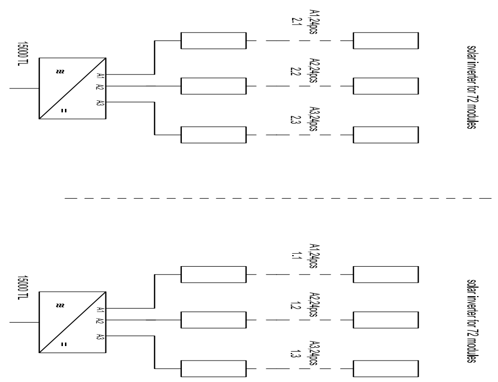


Figure 140: Example for inverter plan and wiring for a 35 kW solar power system

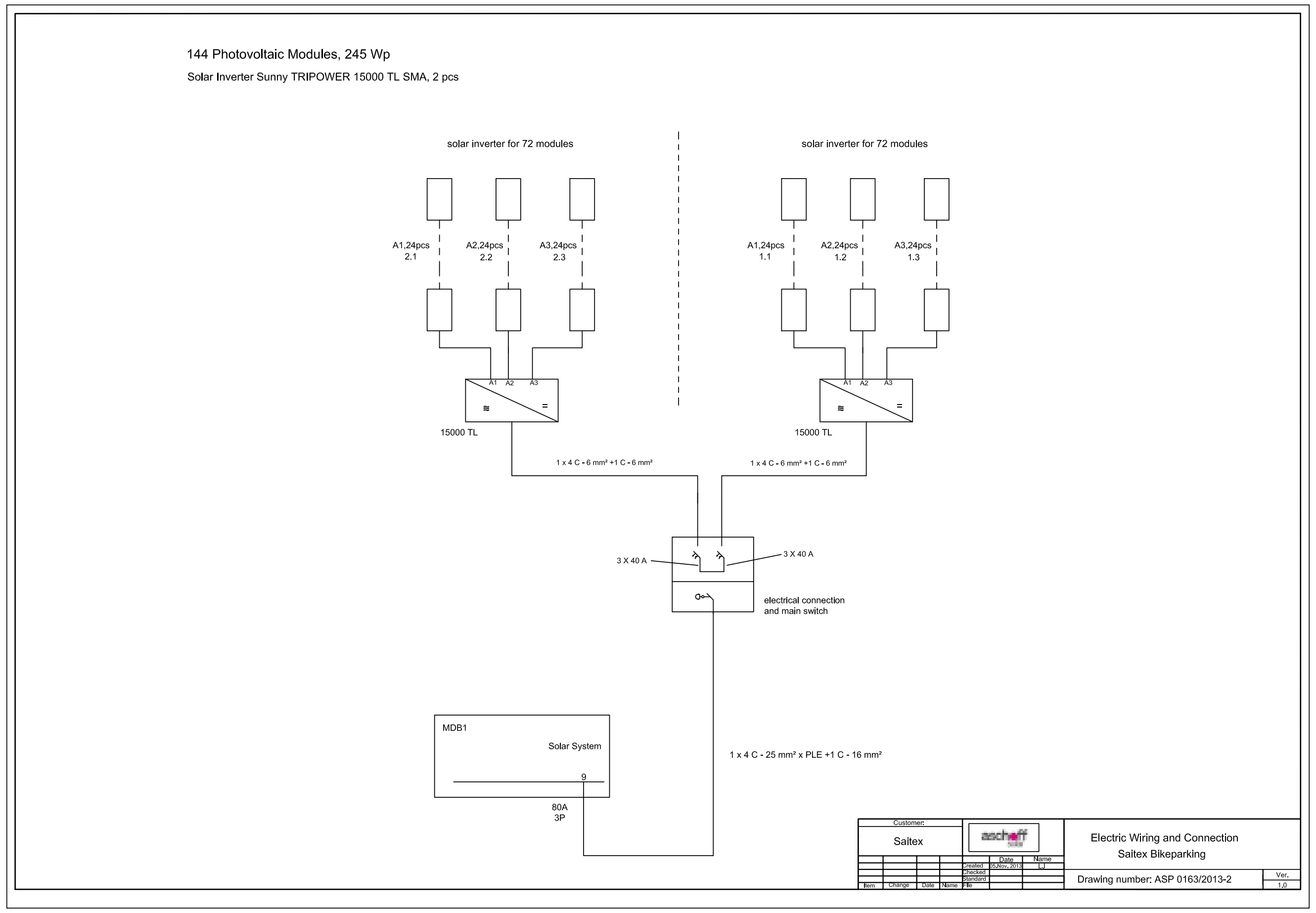


Figure 141: String plan for the 35kWp system

Inquiry regarding a solar plant parallel to the roof – Checklist EN

We thank you for your interest in our systems. Please enter all information requested in the form below to allow us to generate an offer tailored to your specific requirements. Please note: The fields marked with ➔ **are mandatory fields!**

Dimensioning

☐ Cost estimate based on accurate structural analysis
- Very quick processing
- Price tolerance +/- 10 %

☐ Detailed dimensioning
- Dimensioning using the calculator
- Structural verification
- Accurate pricing!

Fastening to the

○ Roof cladding (for example trapezoidal sheet metal)
○ Substructure (rafters, purlins)

Company data

➔ ______ Customer number
➔ ______ Company name

If you are a new customer, please enter your company and contact data

______ Company
______ Street
______ Postal code ______ Town / city
______ Country
______ VAT ID

Contact person

______ First name
______ Last name
______ Telephone
______ Mobile
______ Fax
______ E-mail

Project information

______ Project name

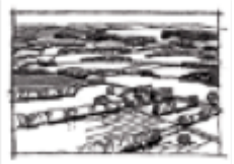
Terrain category

○ Terrain category 0

Sea, coastal area exposed to the open sea

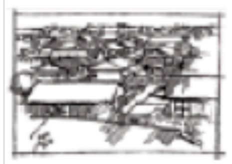
○ Terrain category I

Lakes or area with negligible vegetation and without obstacles



○ Terrain category II

Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights



○ Terrain category III

Area with regular cover of vegetation or buildings or with isolated obstacles with separations of max. 20 obstacle heights (such as villages, suburban terrain, permanent forest)

○ Terrain category IV

Area in which at least 15% of the surface is covered with buildings and their average height exceeds 15m

Geographic data

➔ ______ Postal code ______ Town / city
______ Country
______ Height above sea level (m) ➔ ______ Ridge height above top ground surface (m)

Exposed location
(for example isolated buildings on hills)

○ yes
○ no

Solar plants outside Germany

______ Basic snow load in kN/m²
______ Wind load in kN/m²

Roof shape

○ Pitched roof
○ Shed roof
○ ______

Roof

➔ ______ Alignment
➔ ______ Roof covering
➔ ______ Roof inclination

Figure 142: Questionnaire for the design of the support structure (pitch roof)

Inquiry regarding a solar plant parallel to the roof – Checklist EN

Roof

With trapezoidal sheet metal

______ Sheet metal thickness ______ Distance from crown center to crown center

☐ Aluminum
☐ Steel

With standing seams

______ Seam distance ______ Material

Substructure

○ Rafters, girders (vertical)
○ Purlins (horizontal)

➔ ______ Distances
➔ ______ Material

Module clamping

Clamping at the
○ L - long side
○ S - short side
(Approval by the module producer required)

Module arrangement

○ vertical
○ horizontal

Solar modules

______ Manufacturer
______ Module name
______ Module power (Wp)
➔ ______ Length (mm) ➔ ______ Width (mm) ➔ ______ Thickness (mm)
______ Modules per row ______ Rows

Module layout plan (Sketch of the roof area; arrangement of the modules; with all required dimensions and data; shadowing has to be taken into account; total length north-south, further information, vertical/horizontal mounting)

Figure 143: Questionnaire for the design of the support structure (roof parallel)

Further, the support structure design has to include a wind load calculation, based on the site conditions (e.g. wind zone and height). There should also be a static proof that the system withstands the wind conditions on:

1. Protect from lifting
2. Protect from sliding
3. Protect from tilting

All three criteria have to be checked and confirmed to ensure the static qualification and safety factors of the support structure.

The support structure can be secured for wind via:

1. Sufficient pile drive or concrete foundations for an on-ground installation
2. Sufficient solar fasteners connecting the modules to the roof support structure or roof plates for a roof parallel installation
3. Sufficient fasteners or ballasting for a flat roof installation

Lastly check whether all parts are properly fixed, regardless of the type of installation:

1. Connection to ground or roof
2. Used fasteners or ballasting
3. Support profiles and angles if applicable
4. Module clamps

Due to the physics of wind and the load calculations, the wind speed increases with the height of the building, regardless of the system type and installation. All modules types can be split into multiple parts with different requirements for fixation or ballasting:

1. Corner zones have the highest requirements due to highest wind load
2. End zones also have high requirements
3. Central zones need less ballasting or fixation

In any case, the roof capacity has to carry the load of the solar system including its support structure, ballasting and any additional weight to build against wind load. For on-ground installations it is essential to check, whether the ground is suitable for the chosen foundation (e.g. pile driven or concrete foundations) and if the ground fulfils the specific requirements for the foundations. This has to be done by qualified experts to guarantee the safety of the support structure along the entire lifetime of the system.
For hotels along the coast, it is important to recheck the materials regarding their qualification to withstand sea climate conditions. Salt and chlorides in the air as well as saline water challenge most materials. Therefore, only high quality components suitable for the climate conditions of the project site should be used. In some cases even stainless steel may corrode over a short period of time, if the quality is not suitable for the harsh climate

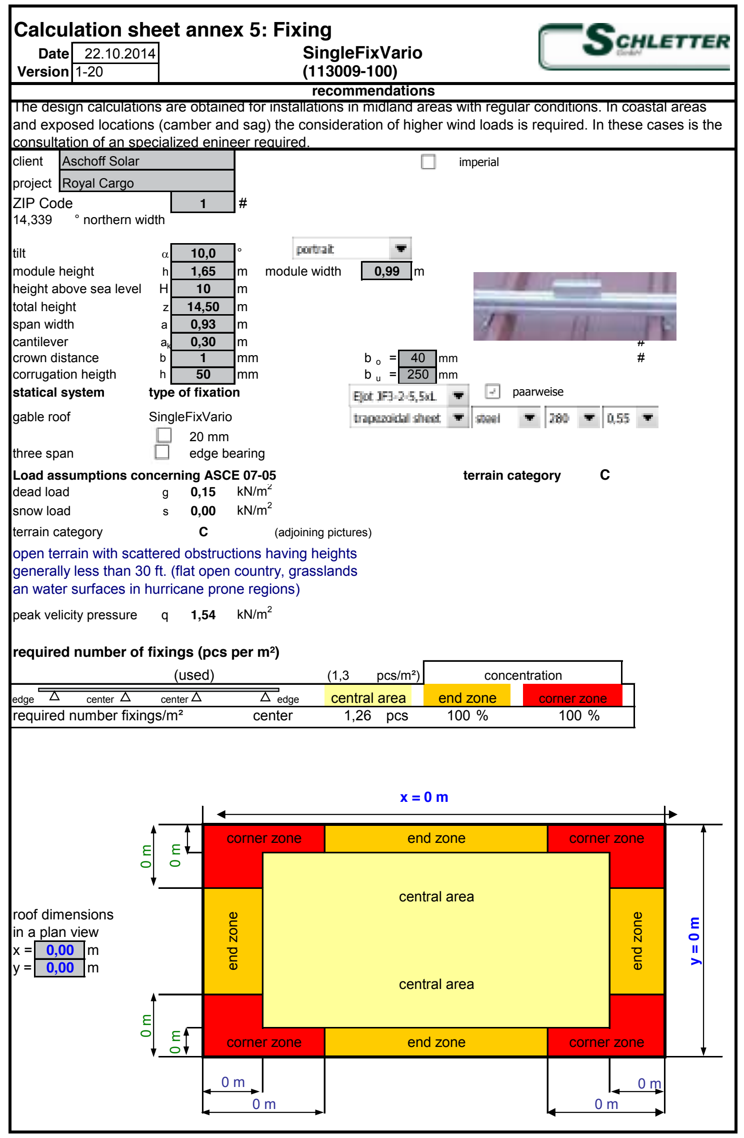
Figure 145: On-ground installations using (1) piles and (2) concrete foundations

Figure 146: Roof parallel installations for pitch roofs with fixation to roof beams and plates

Figure 147: Flat roof installation with ballasting and fasteners

conditions. Galvanized or painted steel structures are usually not suitable to withstand saline water, chlorides and arid climate conditions. Aluminium in combination with high quality steel screws and washers is the preferable choice, despite their higher costs.

Table 8: A wind load calculation for a support structure (extract only)



Calculation sheet annex 5: Fixing
Date 22.10.2014
Version 1-20
SingleFixVario (113009-100)
SCHLETTER

recommendations
The design calculations are obtained for installations in midland areas with regular conditions. In coastal areas and exposed locations (camber and sag) the consideration of higher wind loads is required. In these cases is the consultation of an specialized enineer required.

client Aschoff Solar
project Royal Cargo
imperial
ZIP Code 1 #
14,339 ° northern width

tilt	α	10,0	°	portrait	
module height	h	1,65	m	module width	0,99 m
height above sea level	H	10	m		
total height	z	14,50	m		
span width	a	0,93	m		
cantilever	a_k	0,30	m		
crown distance	b	1	mm	b_o =	40 mm
corrugation heigth	h	50	mm	b_u =	250 mm

statical system **type of fixation** Ejot JF3-2-5,5xL paarweise
gable roof SingleFixVario trapezoidal sheet steel 280 0,55
20 mm
three span edge bearing

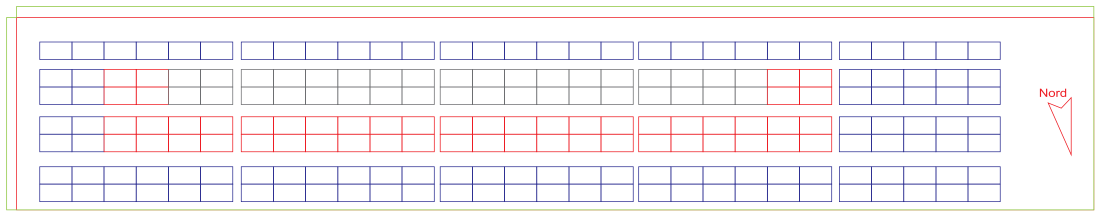
Load assumptions concerning ASCE 07-05 **terrain category** C
dead load g 0,15 kN/m²
snow load s 0,00 kN/m²
terrain category C (adjoining pictures)
open terrain with scattered obstructions having heights generally less than 30 ft. (flat open country, grasslands an water surfaces in hurricane prone regions)

peak velicity pressure q 1,54 kN/m²

required number of fixings (pcs per m²)

(used)		(1,3 pcs/m²)	concentration	
edge center center edge		central area	end zone	corner zone
required number fixings/m²	center	1,26 pcs	100 %	100 %

Table 9: Example of a ballasting plan with different zones



Zone	Ballasting	Size in mm	Qty	weight
(blue)	52 kg	1000/300/80	72	3744 kg
(red)	26 kg	1000/250/50	26	676 kg
(black)	0 kg		0	0 kg
			total load	4420 kg
			specific load	11,05 kg/m2

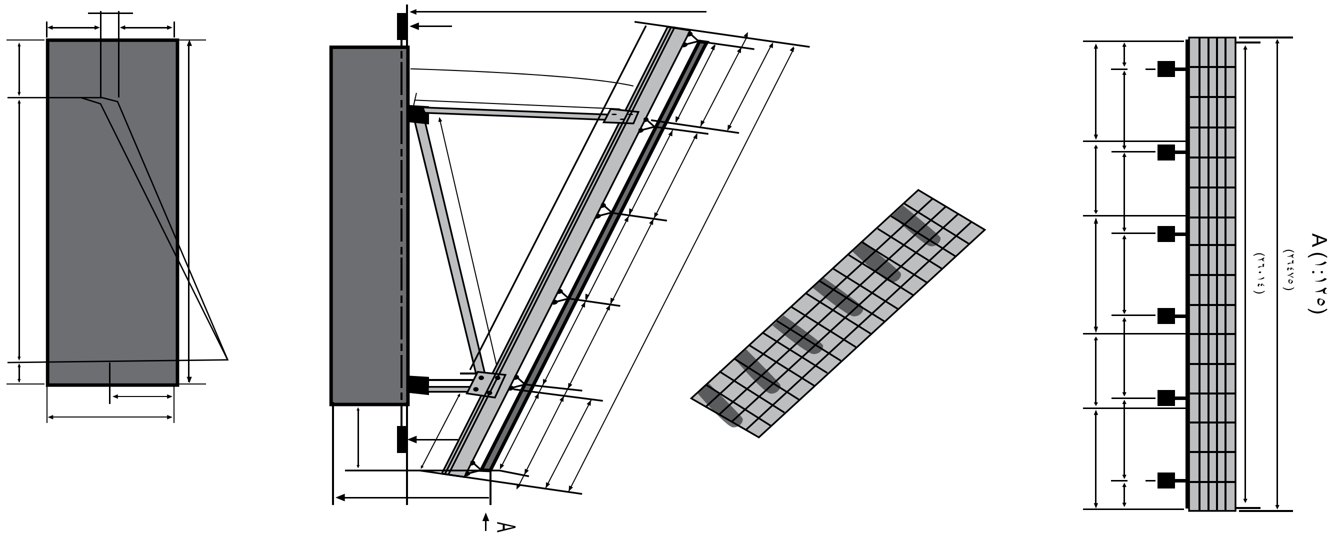


Figure 148: Example of an on-ground support structure based on concrete foundations

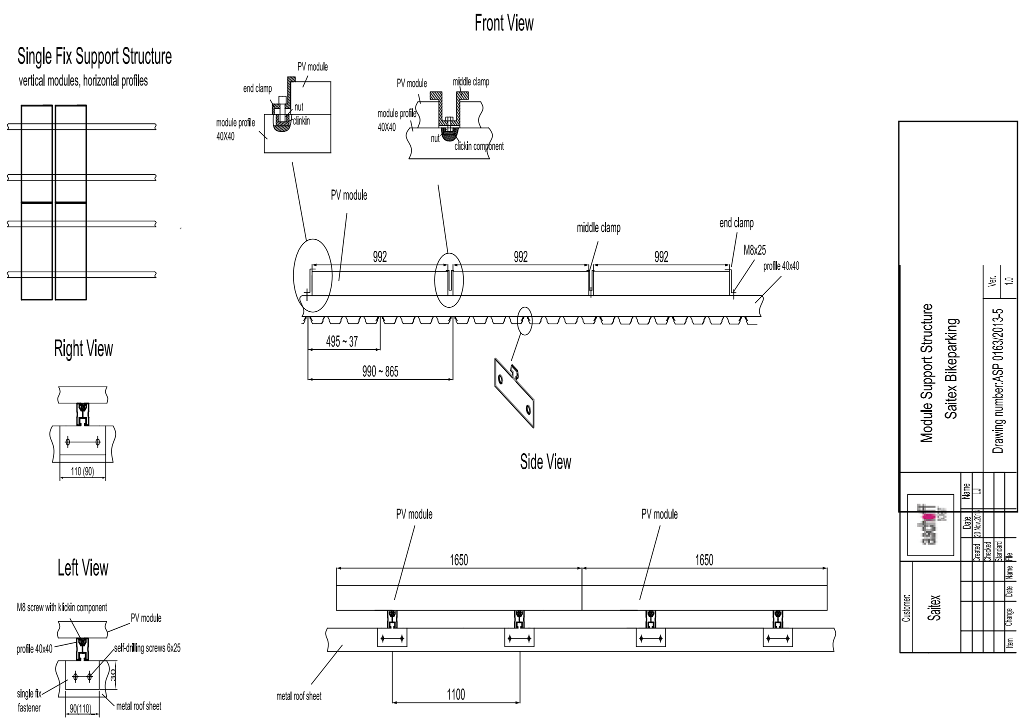


Figure 149: Example of a parallel roof support structure fixed to roof plates

Once the design of the support structure is finalized, the structure has to be integrated into the necessary lightning protection system as well as grounding or overvoltage protection, according to local regulations.

e) Batteries (if required)

The sizing of batteries depends on the application.

1) For short-term storage to balance gaps between solar power and demand during daytime, the batteries can be relatively small. Their required capacity is calculated by the amount of energy in kWh, which is shifted from solar peak times to times, where the demand is higher than the solar power (e.g. late afternoon). Such battery applications are often applied in stand-alone solar systems such as water pump stations.

Under the following assumptions, a system with battery applications (simplified with efficiency of components) requires a battery capacity of 100kWh.

System type: Stand-alone system
Constant demand: 100 kW
Peak power supply: 150 kW for 2 hours on average (at noon time)
Required battery capacity 150 kW – 100 kW)×2h = 100 kWh

The 100 kWh can be used once the solar system stops operating at insufficient sun irradiation. It allows a 1h longer solar operating time of the system.

2) For day/night storage systems that transfer solar energy to the batteries during daytime, in order to operate at night time, the battery capacity is calculated by the required amount of energy during non-sunshine hours. The capacity of the solar power system has to be large enough to ensure full energy supply during daytime and sufficient capacity to charge the batteries in parallel, while taking the efficiency of charging for the batteries into account.

Under the following assumptions, a day/night storage system requires a batter capacity of 1.6MWh.

Constant demand for 24h: 100 kW
Solar operation: 8h equal to 800 kWh
Non-sunshine operation: 16h to 1.6 MWh
Total demand: 2.4 MWH
Average daily power generation: 5 kWh/kWp
Total solar capacity required: 2,400 kWh/day / 5 kWh/kWp = 480 kWp
Required battery capacity: 1.6 MWh

A storage system with a back-up function to ensure operations during power outages requires a battery capacity that covers the minimum power supply for essential consumers for the expected back-up time.
Under the following assumptions, a storage system with a back-up function requires a battery capacity of 200kWh.

Required back-up power at power outage: 50 kW
Required back-up time: 4h
Required battery capacity: 50 kW×4h = 200 kWh

For each system including batteries, it is essential to calculate the nominal required capacity based on the required battery capacity. This depends not only on the battery technology, but also on the ambient conditions of the battery operation. Further, efficiency losses for charging, storage and discharging need to be included in the calculation.

Nominal capacity (kWh) = (capacity (kWh) / degree of discharge for design (-)) / (efficiency of discharging × efficiency of storage)

Typical efficiency factors are:
Lead: charging 88 to 92% Discharging 90 to 92% storage 100%

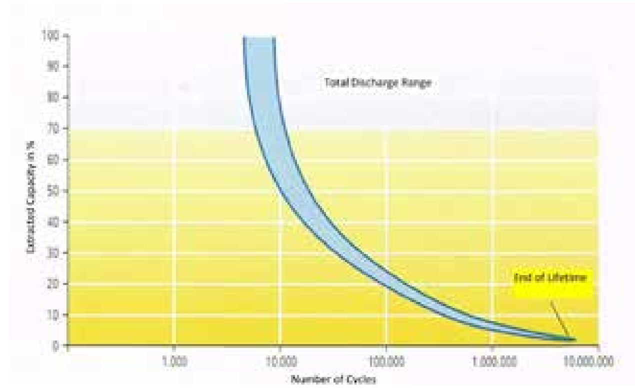
Lithium Ion: charging 94 to 96% Discharging 96 to 98% storage 100%

NaS: charging 82 to 88% Discharging 85 to 91% storage 71%

When calculating the nominal battery capacity, the following efficiency values demonstrate the effect of charging, storage and discharge on the battery's capacity.

Required useful capacity: 100 kWh
Efficiency
Charging efficiency: 90%
Storage efficiency: 100%
Degree of discharge: 50%
Nominal capacity: (100 kWh / 0.5) / 0.9 = 222 kWh

For normal lead based batteries, the maximum level of discharge is 70%, which should not be exceeded. The discharge level can only be exceeded if the supplier gives special releases, as the risk of damaging the batteries by deep discharge is high. Usually, lead batteries are discharged up to 50%, to keep a balance between capacity, space requirement and lifetime. As a general rule, the higher the degree of discharge in operation, the shorter the lifetime of the battery.



Picture 150: Battery lifetime depending on regular degree of discharge

Lithium Ion batteries or other new technologies can reach higher degrees of discharge of up to 80-90%. Yet, their main disadvantages are the higher costs and limited availability on the market. The battery choice is therefore driven by the financial and practical conditions of the system.

The battery supplier indicates the nominal capacity of the batteries at ambient temperatures of 20°C as standard conditions. In case of operating temperatures higher than 20°C, which is usually only possible in air conditioned rooms, the required nominal capacity has to be increased according to the factors given by the supplier.

Regarding the operating temperatures, it is also necessary to consider that the lifetime of the batteries is based on a constant temperature of 20°C and an increase of 10 K[7] can already reduce the lifetime by half. As the capacity of batteries is given in Ah and not in kWh it is helpful to adjust the voltage level of the battery system, already in the design period of the system. Typical voltages are 12V, 24V or 48 V. To calculate the capacity of batteries in Ah, the following equation can be applied:

EQUATION 6:

Capacity in Ah = nominal capacity in VAh / system voltage in V 1

→ Wh = 1 Vah

EXAMPLE 27

Nominal battery capacity

Assumptions:

Nominal capacity: 600 kWh

System voltage: 48 V

Required Ah: 600,000 Vah/4 8V = 12,500 Ah

CAUTION:

Both, over and under sizing the battery system have a negative impact on the operation and the lifetime of the batteries. In case of under sizing there is an increased risk of deep discharging, which leads to the destruction of the batteries, if no deep discharge protection is included in the control. Oversizing leads to insufficient charging and discharging, which leads to a loss in batter capacity, due to the memory effect in the batteries. Despite the battery capacity, for solar applications it is also essential to use special solar-proof batteries, which allow fast and high current charging as well as energy extraction according to the required time and capacity. It is important to involve a battery supplier or experienced solar system designer, in order to ensure that the solar power system, charge control, batteries and demand profiles are aligned for a lifelong operation of the system.

f) Shading analysis and simulation

Shading on solar power systems, even just temporarily, have a significant impact on the solar yield of the system and can reduce the solar power generation up to 10% annually. The shading effects can result from external influences (e.g. trees), surrounding buildings, obstacles on the roof or internal effects, such as shading of solar panels, if the necessary distance between modules has been neglected.

However, shading can also result from dirt on the panels (e.g. leafs, excrements from animals), which cover parts of the generating solar cells. To avoid any performance losses due to shading, it is essential to keep the system clean and to check if any potential sources for shading may occur already in the design period prior to installation. In fact, shading caused by closely located obstacles on the roof (e.g. air-conditions), a so-called core-shadow reduces the irradiation to the panel by up to 60%. Partial shadows with longer distances to the panels do not reduce the irradiation as strongly, but should also be taken into account and if possible avoided.

The optimized distance (ie. Aopti) between the panels and the obstacle can be calculated based on the thickness of the obstacle d by using the following equation:

EQUATION 7:

Aopti = 108 × d

For a flag with a diameter of 20mm, the optimized distance to avoid shading is
= 108 × 20mm = 2.16m

Shading Analysis

A shading analysis should be applied to identify all potential sources for shading at different daytimes and seasons, prior to the design of the module arrangement. For such an analysis, it is necessary to fix one or several points in the expected solar area and identify the height and distance of obstacles surrounding the area in all directions. Based on the position of the sun at different daytimes and seasons, it should be analyzed if any obstacles cast shadows onto the system. The analysis is usually done via professional software tools (e.g. PV-Sol) or special equipment (e.g. SunEye or HORIcatcher), which are highly advised for larger systems.

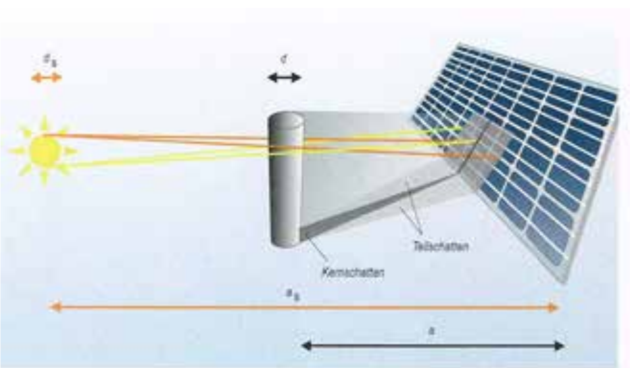


Figure 151: Core and partial shadow

g) Generators (if required)

If generators are used within a solar system as a supplementary or back-up power source, it is crucial to choose generators that allow flexible control and operations in a wide power range. Simple one-stage on/off generators should be avoided. Further, accurate sizing is also an important factor. It is misleading to assume that oversizing the system will secure safer and better operations. As a matter of fact, it only lowers the efficiency of the generator, since the generator will rarely operate on its nominal power with optimized fuel consumption. As a result, an oversized system leads to higher fuel consumption and a reduced generator lifetime. An external control with suitable interfaces for a solar or central control system should be included, to allow a proper integration of the generator into the solar system.

h) AC connection

The AC connection for a solar power system strongly depends on the size of the system, the solar fraction to the total demand as well as to the local regulations of the utility. For small-scale systems in a range of up to 50 kWp, it is often sufficient to install a relatively small unit including the following devices:

- Circuit breakers for every inverter connected (sizing according to datasheets of inverter)
- Communication device
- Overvoltage and surge arresters (if applicable)
- Main load break switch to disconnect the solar system

Additional to the AC connection unit, an additional load break switch for the complete solar power system in the main- or sub distribution board is necessary. The load break switch is sized according to the total current of the system.

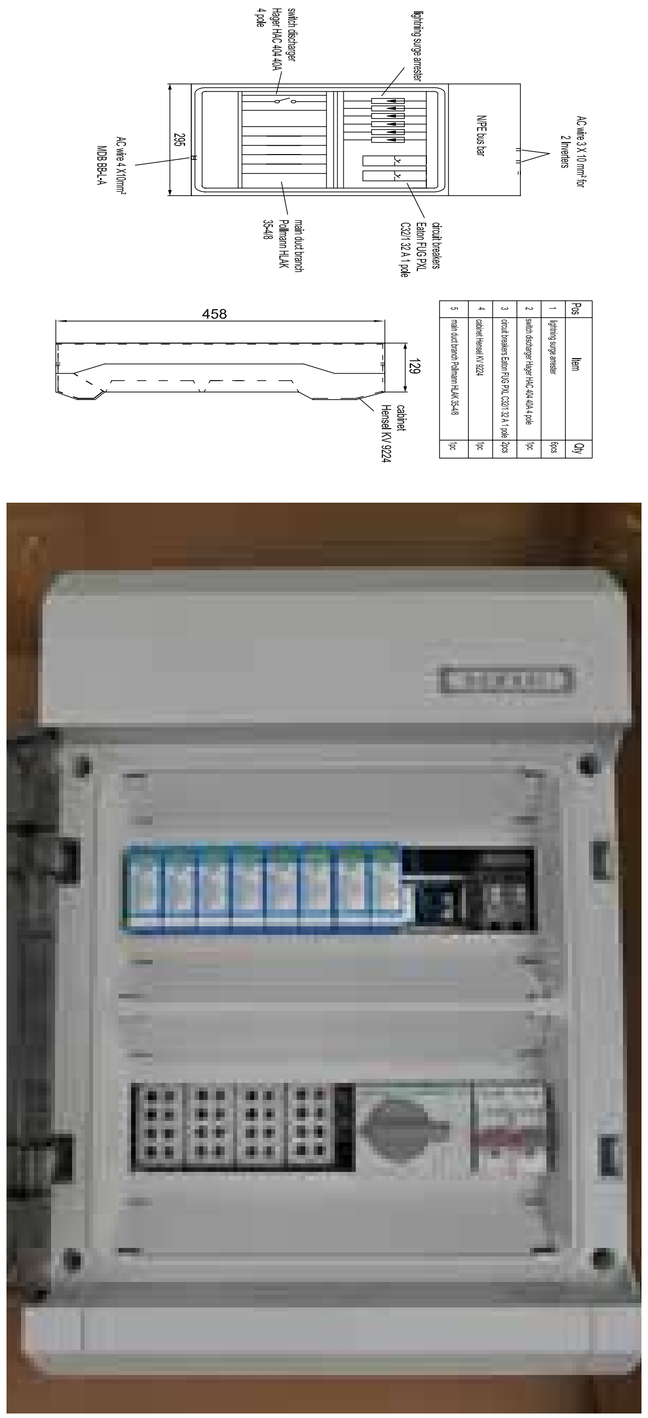


Figure 153: AC connection unit for small-scale solar power systems without special control functions

[7] Kelvin

Figure 154: AC connection unit for a 250kWp solar power system with a matching transformer

i) Component location

The location of the necessary components, such as string boxes, inverters, control systems ad AC connections, has to be according to the recommendations and instruction of the attached manuals of the suppliers. Especially ambient temperatures, humidity and direct sunshine are factors, which influence efficiency and lifetime of the system. For the AC connection unit it is reasonable to place it close to the MDB[8] to keep the main AC wiring short. Inverters and string combiner boxes should be installed close to the module areas to keep losses in wiring low. Regarding ventilation grids and cooling elements, it is best to have them free and separate from any other components to ensure the accurate cooling function. Inverters should not be installed on any flammable materials.

To manage possible noise of the system components, it is most favourable to keep them away from direct contact to public guest areas or close to the guest rooms, if no noise abatement measures are taken. If installed outside, the protection class of the inverter must withstand outdoor weather conditions and the components should be covered from direct sunlight. A small hut, in which all components are installed, is an easy and economic solution, to protect from noise and sunlight.

Figure 155 connection unit for industrial medium voltage systems

Figure 156: AC connection unit of a MW system (SMA utility power system)

4.2 TECHNICAL SPECIFICTIONS FOR SOLAR POWER SYSTEMS

4.2.1. COMPONENTS OF SOLAR POWER SYSTEMS

[8] Main distribution board

Important Notes:

- The operating voltage of solar power systems can be up to 1500V DC
- During sunshine, the system is under voltage
- Only specialized personnel are allowed to work at the solar system
- Only tested and certified components should be used
- Only use components suitable for the environmental conditions at the project location
- The solar system lifetime is up to 25 years
- All materials and components should be designed and installed according to the lifetime of the solar system

Photovoltaic modules

The PV modules generate the solar power by converting solar irradiation to electricity. Crystalline or thin-film modules can be applied, according to the design, weather conditions, available space and budget.

Crystalline modules are the standard modules, applied in approx. 90% of all cases. They offer the best price-performance ratio under normal operating conditions. All crystalline modules are made out of silicon. Monocrystalline have a higher basic efficiency compared to polycrystalline modules. Regardless of the type of crystalline modules, all cells are cut in thin plates from so-called wavers, which are made out of pure silicon. PV modules get the ability of generating power by solar irradiation, through a special chemical treatment of the wavers. The power generating solar cells are usually embedded (i.e. laminated) between a front-glass and a back sheet film and framed in an aluminium frame of a thickness between 30-50mm.

Special all glass modules, in which the solar cell is between two layers of glass, can also be applied. This is mostly used for solar system installed at façades or used as semi-transparent covers for greenhouses or terraces. A typical module has 36-216 cells and a power output of 250-320Wp. Polycrystalline modules usually have a blue shining surface and the structure and border between crystals are visible on the panel surface. Also, the gaps between the corners of the cells are well visible. Monocrystalline modules on the other hand are black or dark blue with a homogeneous surface. Contrarily to the polycrystalline modules, the gaps at the corners of cells are usually much smaller.

The efficiency of monocrystalline modules is higher than any other module technology, which is reflected in their surge price. Its material is purer compared to other module types, which positively affects the efficiency of the panels. The polycrystalline module efficiency is a few per cent lower, however due to the lower price, they usually have a better price-performance ratio. Thus, in most cases polycrystalline modules are installed and only when the space for the installation is very limited, monocrystalline PV panels are the preferred choice.

Figure 158: PV Cells – Monocrystalline and polycrystalline

A third panel technology is the so-called thin-film technology. Thin-film modules are using a different technology, which could be described as coating or sputtering a very thin solar active surface on a carrier material e.g. glass. Different technologies can be applied, such as CdTe or CIS. Thin-film modules usually have a lower efficiency compared to crystalline modules of approx. 50%. Thus, for the same solar output, twice the size for the installation area is required. However, thin-film modules also have some advantages. In case the orientation of the solar modules is not optimal or the temperatures are high, thin-film technology loses less of its power output under higher operational temperatures. The thin-film panel can use a wider range of solar irradiation and is more effective at higher diffuse irradiation, such weather conditions with fine dust in the air. Also, there are various colours available of thin-film modules that can be visually nicely integrated into façade installations. Nevertheless, these modules also have some disadvantages, one begin the use of heavy metals, such as cadmium or arsenic, challenging the recycling and disposal at the end of the panel's lifetime.

Figure 158: Installations of polycrystalline modules

Over the past years, mass production and decreasing costs for crystalline modules lead to the thin-film modules having a lower price-performance ratio for most projects. They are therefore currently not competitive, unless high aesthetic requirements such as surface colour is required or the project is located in very hot climates without space limitations (e.g. desert applications). Thin-film modules are available in different colours, such as black, brown or red and have a homogeneous surface with vertical lines (figure 159 & 160).

Figure 159: Thin-film module

Figure 160: Installation with thin-film modules

Poly- and monocrystalline have a minimum lifetime of 25 years. For thin-film technology, especially new module types, insufficient data is available to receive long-term warranties from suppliers of over 20 years.

All module types have a yearly performance loss called degradation or aging effect of 0.5-1%, depending on the modules' quality. The solar system provider usually decides on the most suitable module type for the project during the design phase. There is no general rule applied when deciding for the right PV module. It is rather the question of how many modules per string and how many strings in parallel build up the solar array, which is an integral part of the design phase. It is in the responsibility of the system provider to ensure a well functioning system and a safe combination with the inverters over a wide range of possible weather conditions at the project's site. An overview of the module types characteristics is given in table 9.

For all module types, it is important to know its technical data and characteristics, in order to calculate and simulate the performance under various operating conditions. As modules reduce their output under higher operating temperatures, it is crucial to choose modules with lower temperature coefficients, thus lower decrease of output with higher temperatures. The temperature effect on the performance of the system is a key factor for solar applications in particular in the MENA-region. Slightly oversizing the system is a possible solution to overcome the losses due to high ambient temperatures. In operation, the system output is usually slightly lower than its nominal power in kWp[9], which serves more as a figure for comparison between systems.

Table 9: Various cell material and their specifications (Source: Fraunhofer-Institute for Solar Energy Systems ISE)

PV cell technology		Best module efficiency (%)	Power degradable (%/years)	Temperature coefficient of power (%/°K)	Required PV area for 1kWp
Crystalline	Mono silicon	19.6%	-0.25	-0.37 – 0.52	7-9m2
	Poly silicon	18.5%	-0.25	-0.37 – 0.52	7.5-10m2
Thin-film	Amorphous silicon	8.7%	-0.5	-0.10 – 0.30	14-20m2
	CIGS	11.3%	-0.5	-0.39 – 0.45	9-11m2
	CdTe	11.1%	-0.6	-0.20 – 0.36	12-17m2

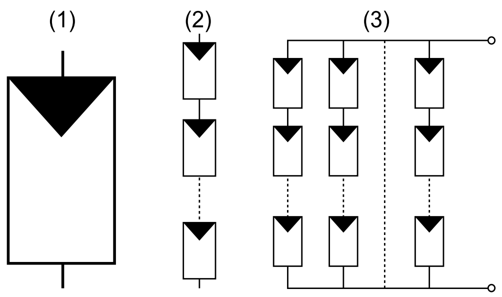


Figure 162: Symbols for a (1) PV module, (2) PV string, and (3) PV array

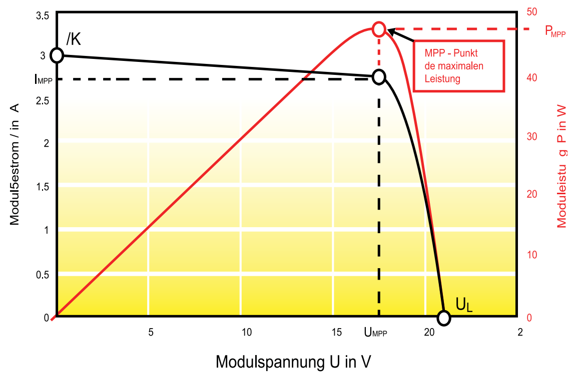


Figure 163: Power curve - Maximum Power Point

[9] Kilowatt peak

The module characteristics, regarding the voltage U (volt) and current I (ampere) under different operation condition (e.g. irradiation and temperature) are given in their datasheets, displayed as diagrams and/or coefficients in %/K or mV/K, mA/K. The power P (Watt) is the product of current and voltage. The power curve plotted in dependence to the voltage reach a maximum at the so-called maximum power point (MPP). The MPP is the most intense power reached by the PV module in a certain time span (figure 133). The MMP is an important factor in combination with the MPP tracking system (i.e. a key function of the solar inverter). Each solar panel, regardless of brand or technology, has similar characteristics. As a rule of thumb for all solar systems, the higher the irradiating the higher the output current of the panel.

When designing a solar system, local irradiation conditions need to be taken into account. Not only at perfect irradiation, but also the minimum and average irradiation have to be considered to ensure stable and safe operations at the most optimal efficiency.

Another constant in solar panels is, the higher the temperature of the modules, the lower the efficiency. This is a very important issue with regard to voltages in the solar system and string design. The temperature effect on the output of the panels and the therefore resulting voltage has to be adjusted to the input range of the inverters. Solar designs require both know-how and experience to optimize systems for extreme weather conditions in the desert. The characteristics of the modules are usually described in the product datasheets and are given as standard values and temperature coefficients in %/K, mV/K or mA/K. These values indicate the decrease of voltage/current/power per degree deviation of operating conditions from the STC . A simulation and design of the system must include these factors:

- Technical data under STC, nominal power, Vmp, Imp, Vocm, Isc
- Temperature coefficients in Pmax, Voc and Isc in %/K or %/°C
- Operating temperature range in °C
- System voltage in V
- Power tolerance in %
- Dimensions
- I-V-characteristic curves
- Type of connectors
- Certificates
- Warranty conditions

Most manufacturers also indicate the NOCT data (Normal operating Cell temperature) in the datasheet of the panels, as the STC conditions are not a realistic representation of the panel performance.

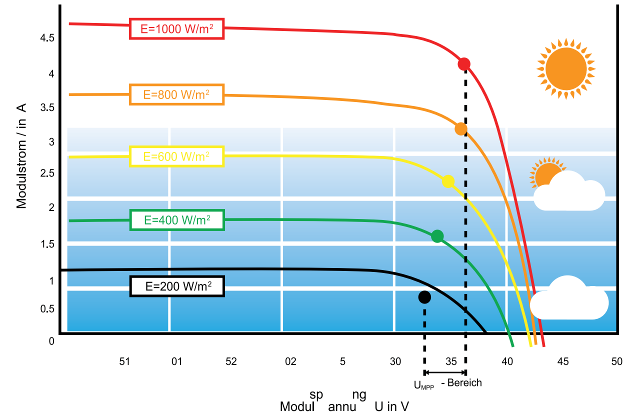


Figure 163: Output of a PV module depending on irradiation

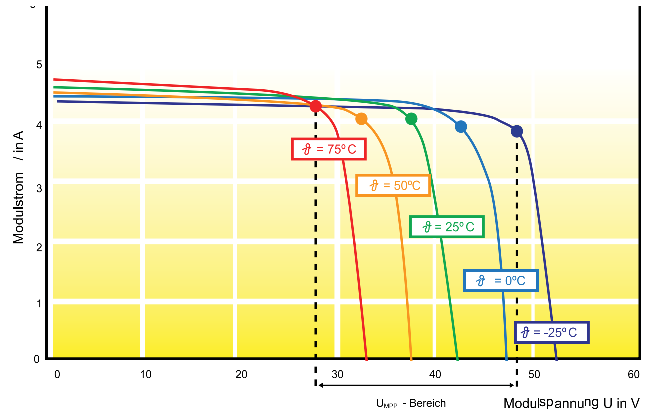


Figure 164: Output of a PV module depending on module temperature

EXCURSION 7
TECHNICAL DATA OF MODULES

Pmax: Nominal maximum power under STC in W

Vmp: Voltage at maximum power point under STC in V

Imp: Current at maximum power point under STC in A

Voc: Open circuit voltage in V under STC

Isc: Short circuit current under STC in A

[10] Standard Test Conditions: 1000W/m², 1.5 spectrum AM(air mass), ambient temperature of 25°C.

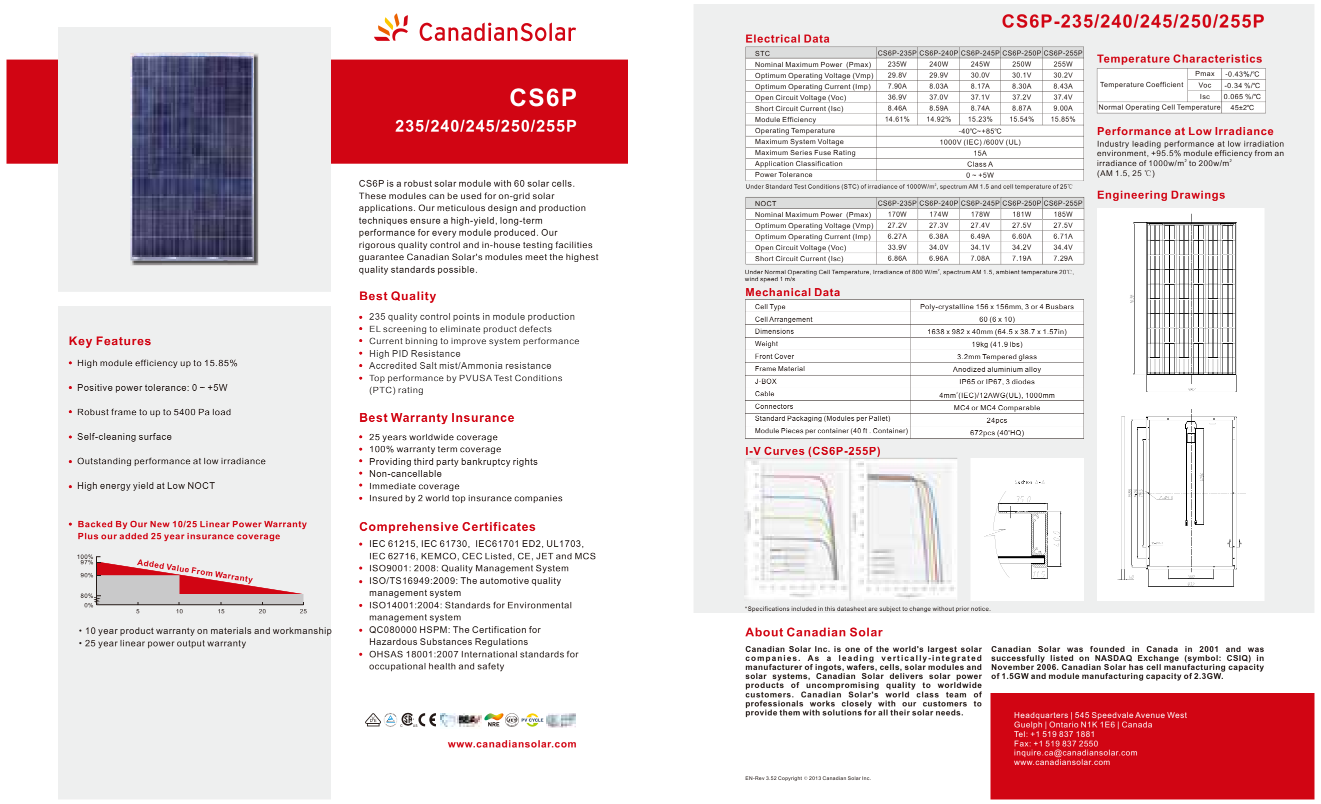


Figure 165: Example of a crystalline module datasheet

Figure 166: Example of a thin-film module datasheet

PV panels are equipped with module connection boxes on their backside, which serve as the interface between the panel and the system as such (figure 167). The boxes include important bypass diodes that ensure the operation of every single cell. Also included is the module wire, which connects the modules to each other, to the string box and to the inverters directly. These module wires should be long enough in order not to create tension on the system. It is highly recommended to only use certified and waterproof PV connectors.

Figure 167: Module connection box at the backside of a PV module

Essentials for PV modules:

- Good price-performance ratio
- Temperature coefficients as low as possible
- Range of allowed operating temperatures must fit to on site conditions
- Connection boxes and lamination have to be stable under high operating temperatures
- Suitable packaging to ensure safe transportation

Required standards for PV modules:

- IEC 61215 PV modules with crystalline cells (or equal UL 1703),
- IEC 61646 thin-film PV modules
- IEC 61730 safety qualification of PV modules
- Module connection box minimum IP 55 or IP 65 (category 1 acc. to EN 60259), Protection class II
- EN 50548 connection boxes for PV modules

Special requirements for modules in the MENA-region:

- Suitable for high operating temperatures
- Withstand periods of strong sandstorms Withstand sea-climate conditions if installed in coastal areas

Support structure

Although often neglected, the support structure of a solar power system plays a significant role. It is decisive for the lifetime and safe operation of the system. The support structure of a solar power system is necessary to fix the PV panels onto the roof or ground. Since it has to carry the weight of the solar system and any addition weight to protect against wind loads, it has to be designed according to the weather conditions of the project's location to ensure the system's safety and reliability. The support structure should use anti-corrosive materials, such as aluminium, galvanized steel or stainless steel. Caution, at hotels along the coast, the structure should be made out of special stainless steel that can withstand salinity and chloride, such as steel used for boatbuilding or aluminium. Even high quality stainless steel, such as 1.4404 does not resist the sea climate over a longer period of time. Otherwise, high-level stainless steel and aluminium in combination with stainless steel screws are the preferable choice, according to long-term experiences in Europe. Further, it has to be ensured that the materials mixed are safe and do not cause contact corrosion (e.g. stainless steel screws with steel washers).

The support structure has to be designed according to the following criteria:

- Safe and stable structure
- Designed based on the weight of modules according to wind load conditions
- Designed for a lifetime of more than 25 years
- Only use anti-corrosive materials
- In case the system is visible to the hotel guests, structure should be visibly integrated into the hotel's architecture

The support structures for hotel applications can be divided into the following:

- Pitch roof systems (e.g. on office, warehouse or generator housing)
- Flat roof systems (e.g. on office or generator housing)
- On-ground field installations
- Special structures e.g. car ports or roof shades

Pitch roof systems:
A pitch roof is a roof with a certain inclination to the horizontal in one or two directions (picture 139). For a pitch roof installation, the PV modules are installed parallel to the roof plates on either horizontal or vertical support profiles, depending on the structure under the plates. The connection between the roof structure and plates is done with standard fasteners according to the roof type.

Figure 168: Typical pitch roof installation

Figure 169: Support solutions for roof parallel installation

For safety reasons and to ensure sufficient ventilation, it is important to include some additional space at the roof edges. The pitch roof installation is normally the most cost-efficient solution, as no foundation or ballasting is required and the system can be fixed on an existing structure. The PV modules have to be secured on the support structure via qualified module fasteners, which are widely available for any PV module type (picture 141).

Flat roof systems:
For flat roof installations, the PV modules are installed at a certain inclination to optimize the solar yield and simultaneously have a self-cleaning effect at rainfall (picture 142). Depending on the roof structure, the support structure is fixed directly to the roof beams, which require special sealing technology. Usually simple ballasting via concrete blocks on rubber mats is sufficient to ensure stability.

Figure 170: Standard module fasteners

Figure 171: Typical flat roof installations

In particular for flat roof installation, it is important to keep minimum space between the rows of modules to avoid self-shading between them. The minimum distance to avoid shading even during winter months, when the position of the sun to the horizontal is the lowest (e.g. in Cairo 35°), can be calculated as follows.

EQUATION 8:

$$d_{min} = b \times \sin(180° - \beta - \gamma) / \sin \gamma$$

dmin = Minimum distance between the front edges of each module

b = height of PV module (m)

β = inclination of modules (°)

γ = angle of sun to the horizontal in the winter (°)

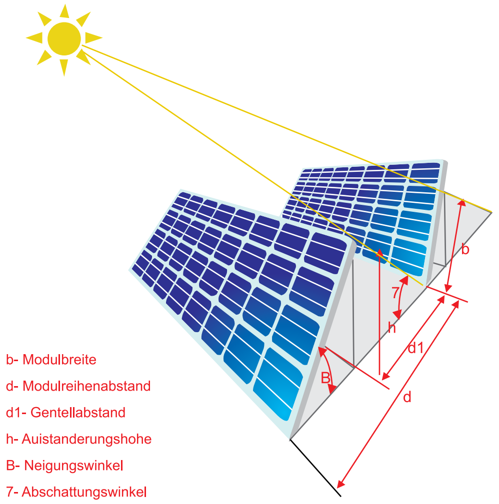


Figure 172: Required distance between PV module rows

EXAMPLE 27
Required distance between PV modules

Dmin:	1,32 m
b:	1m
γ:	36.55° (near Cairo – 30. 2 N)
β:	15°

The angle of the sun in the winter season for the northern hemisphere can be calculated as follows (simplified):

Cairo, latitude 30. 2 North

γ = 90° - latitude - 23.45°
γ = 90° - 30° – 23.45° = 36.55°

Another important issue for flat roof systems is the assurance of a maximum additional static load for the existing roof and the calculation of necessary ballasting. Additionally, the roof's weight capacity and the system load have to be rechecked. In case the load for the roof is too high, ballasting can often be reduced by some optimized standard systems available on the market.

On ground field installations:

Hotel applications as on-ground field installations are necessary, whenever space on roofs is occupied or large scale MW system are planned. Two types of foundations can offer the necessary support structure on the ground: (1) pile and (2) concrete foundations. The concrete strips require the angles of the support structure to be fixed with screw anchors to the concrete. For both types of foundation, knowledge and soil analyses are necessary prior the installation to guarantee the stability of the system over the entire project lifetime.

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Figure 173: Solar on-ground installation with concrete foundations in Bahareyia, Egypt

Figure 174: Solar on-ground installation with pile foundation

Regarding shading effects, the same rules as for flat roof installations apply. A minimum distance between two rows of modules of approx. 0.5m is required (figure 173). Also important for an on-ground installation, is to keep a minimum height of the front edge of the module to the ground to be able to cut the grass and plants underneath the system.

Special support structures:

An interesting option for hotels is the inclusion of solar panels into existing facilities. Solar system support structures can be integrated as shelters on the golf course, as carports or other shading materials in the hotel resort. In Germany, special support structures are already an integral part of the architecture of many farms, corporate buildings and hotel. Therefore, many components for special support structures are already available on the market, offering cost-efficient solutions to increase the solar output of system in existing buildings. The economic benefit of special support structures (e.g. shading for terrace) is the double function of the solar system, in which PV modules replace otherwise needed materials whilst generating solar power (figure 176).

Essentials for support structures:

- Use anti- corrosive or protection against corrosion materials

Figure 175: Solar systems on farm and carports

- Static calculation of the structure
- Remain required distance between solar arrays to avoid shading effect
- Existing roofs have to be well sealed to avoid any leakages, which are difficult to repair once the solar system is installed

Figure 176: Sun terrace covered with semi transparent glass-glass modules for shading and power generation

Figure 177: On-ground installation, roof top installation

Figure 178: Standard Solar Connectors (Source: Multi-Contact)

Essentials for support structures:

- Use anti- corrosive or protection against corrosion materials
- Static calculation of the structure
- Remain required distance between solar arrays to avoid shading effect
- Existing roofs have to be well sealed to avoid any leakages, which are difficult to repair once the solar system is installed
- Static check of existing roofs
- Include structure as shading elements

Required standards for the support structure:

- Calculations according to DIN EN 1991 impacts on support structures
- DIN EN 1990 basic standard for support structures
- DIN EN 1991-1 aluminium structures
- DIN EN 1993-1 steel structures

Special requirements for support structures in the MENA-region:

- Withstand periods of strong sandstorm
- Withstand sea-climate conditions if installed in coastal areas
- pport structure must fit the architecture of the hotel (if visible)

DC Wiring

DC wiring connects the power strings of the system to the inverters. The power strings can be either connected through (1) string boxes or (2) directly connected to the inverter(s). (1) The string box serves as an interface between the power strings and the inverter(s) and connects the components via the main DC wiring. (2) In a direct connection, the power strings are directly connected to the inputs of the inverter(s). All wires have to be sized and chosen according to the environmental and operating conditions and must be suitable for outside usage (e.g. UV resistance and temperature resistance). For DC wiring only, special solar wires are used that have been specifically developed for outdoor applications under special conditions of a PV system, such as high voltage and temperature. All wires that are used for outdoor installations have to be protected by suitable protection pipes or cable ducts (figure 178).

Figure 179: Wire protection via cable ducts

String combiner boxes are used, depending on whether several PV array must be connected to one input of an inverter. The string boxes must meet the local safety requirement according to IEC 62103 and include the following devices:

- DC fuses for each string
- DC circuit breaker
- DC overvoltage protection (if not already provided by the inverter)
- Connection to lightning protection
- Terminals for connection of strings and inverter input

A string combiner box allows safe disconnection of the solar power modules from the inverter in case of necessary work at the system.

The modules and strings of a solar power system are under high voltage as long as solar irradiation is available. Disconnecting the DC side from the inverters is only effective at the inverter on the AC side. PV modules are still under voltage.

Essentials for wiring and accessories:

- Only use certified and tested products for solar power systems
- Sizing according to environmental conditions at hotel site

Figure 180: String combiner box in a solar power system

- Protection level according to place of installation
- Installation protected from dirt and insects
- All products have to fit high DC voltage (600V to 1500V)
- Safety First!

Required standards for accessories:

- IEC 62103 - Electronic equipment for use in power installations

Inverters

The solar inverter is the key component of a solar power system. It is the intelligent interface between the DC (direct current) solar power generation and the AC (alternating current) power at the grid.

An inverter has to carry out the following tasks:

- Transfer DC into AC power
- Adjust operations according to the MPP of the PV modules
- Adjust solar power to the demand of the consumers in case of a direct connection from the solar system to a consumer
- Adjust solar power output to the generator (in case of a hybrid system)
- Synchronize solar power generation with the public or generator grid
- Create an own stable grid (in case of an island solution)
- Collect operating data and visualize status of operations
- Include protection devices at DC and AC side

Figure 181: Different inverter installations of outside and inside solar systems

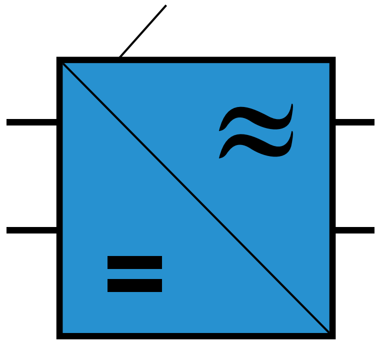


Figure 182: Symbol for a solar inverter

Inverters include one or several MPP trackers. The trackers ensure that the solar modules are always generating the maximum power according to the actual irradiation and ambient conditions. If only one MPP tracker is included, the strings of the solar array are connected to a string connection box coupled to a single input. When string inverters with several MPP trackers are used, the strings are directly attached to the inverter, which allows linking areas with different orientation and shading to different MPP trackers. The result is a more accurate tracking and therefore higher system efficiency. For roof installations where PV panels are installed at different angles to optimize their orientation and inclination, it is recommended to use several MPP trackers.

Modern inverters usually include interfaces to monitor single strings and devices to protect against overvoltage from the DC and AC side. Today, remote access to the inverter monitoring system via the Internet is standard, which helps to identify if any maintenance or adjustments are needed.

Figure 183: Standard inverters for grid connection

A power management function to reduce the solar power when necessary is important, whenever the inverters are embedded in a hybrid system (e.g. fuel saver solution). In larger self-consumption systems, a central control manages the solar output to the generator power, in case no feed-in tariff or net-metering policies are in place. If a solar back-up system or complete independent solutions are installed, special island inverters are required in addition to the standard inverters. Such inverters are designed to create an own stable grid and play the dominating role within the power generation. Any other power source has to be connected to an additional control and synchronized with the created grid of the solar power system.

Figure 184: Island inverter for grid connection
(Source: SMA Solar Technology)

Most suppliers are separating the functions of the standard grid connected inverter and the island inverter to create an independent grid. However, there are also devices available, which include all necessary functions for off-grid systems in one intelligent component. The most suitable solutions depends on the individual project.

Figure 185: Solar inverter, island inverter and charge control in one unit

Another special type of inverters is the micro inverter. Micro inverters are connected to a single PV module and transfer the generated DC power directly into AC (figure 186). Several micro inverters transfer the AC power to the internal grid. The advantage is that even very small, decentralized power units can be connected to the internal grid, which is very useful for hotels with a bungalow structure, where just a few PV modules are installed per bungalow. Regular inverters would be too costly to install and inefficient with much of their capacity unused.

Figure 186: Solar micro inverter for single PV modules

Essentials for solar inverters:

- For systems with a grid connection install only certified standard inverters
- Have to be efficient also under high ambient temperatures
- For systems with direct connection to a consumer only island inverters with integrated frequency control should be used
- Only inverters designed for operating under high ambient temperatures are suitable
- Standard inverters always need another dominating power source to synchronize
- Integrate MPP tracking
- MPP range of inverter has to fit MPP tracking of used PV modules and string design

Required standards for solar inverters:

- IEC 62103 Electronic equipment for PV power installations
- IEC 62109 Safety of power converters for PV power systems –
- Part 2: Particular requirements for inverters

Special requirements for inverters in the MENA-region:

- High ambient temperatures
- Withstand sea-climate conditions if installed in coastal areas
- Installation protected from sand and dust
- Operating voltage and frequency range must fit to local grid conditions
- Robust technology preferred

AC Wiring

The AC wiring in a solar power system connects the inverters with the AC connection unit and the main- or sub-distribution board of the hotel. The main distribution board requires a suitable load break switch to connect to the inverter. Depending on the design, additional power metering must be installed to monitor the demand, if e.g. a power management function in combination with a generator is implemented. The sizing of the AC wiring must take the ambient temperatures into account and should keep losses in wiring as low as possible. Open wires should always be protected from any external influence (e.g. sunshine exposure) through protection pipes or cable ducts.

Despite the requirement for overvoltage protection at the AC side of the inverters, there are no additional requirements when using a solar power system. The wiring for a solar system is no different than any other AC installation in the hotel.

AC connection unit

Next to the inverter, the AC connection unit is another key component of the solar system. It is a crucial component to assure stable and reliable operation. The AC connection unit has to include all necessary control and safety devices according to the size of the project. The role of the AC connection is to combine several inverters to one unit and to connect these to the main distribution board of the hotel. For smaller systems, the AC connection unit includes circuit breakers for each inverter, a main switch to disconnect the system from the grid as well as an overvoltage protection, if necessary.

For larger systems, the AC connection unit includes the

Figure 187: AC connection unit for a small size solar power system

following additional features:

- Grid and system protection – a function which includes a monitoring system to observe the quality of the grid and disconnect the system safely in case of any disturbances
- Functions for power management
- Functions for consumer management (e.g. on/off switch in case of solar excess/lack)
- NH fuses and disconnection devices for single and complete set of inverters
- Metering, monitoring and communication devices

Figure 188: AC connection unit for a large-scale solar power system

Within the main- or sub-distribution board of the hotel a separate load break switch has to be installed to connect to the AC connection unit.

The load break switch allows a safe disconnection of the solar power system and a continuation on the conventional power source during repair and maintenance.

Solar power control and monitoring

A solar power system operates fully automated and does not require any active control by an external operator. The solar power control is limited to the monitoring of the system regarding the achieved solar yield and for preventive maintenance measures, in case no special functions, such as control of a hybrid system or power and consumer management are included (picture 160). The solar control system is in form of a data logging and visualization software and includes the operational control and monitoring function:

- Data logging and visualization via an Internet portal (e.g. laptop, tablet, smartphone)
- Sensors for irradiation, temperatures and wind
- Visualization software
- A display in the hotel lobby (optional)
- Connection to building management system (if required)

Figure 189: Data logging and communication devices in a solar power system

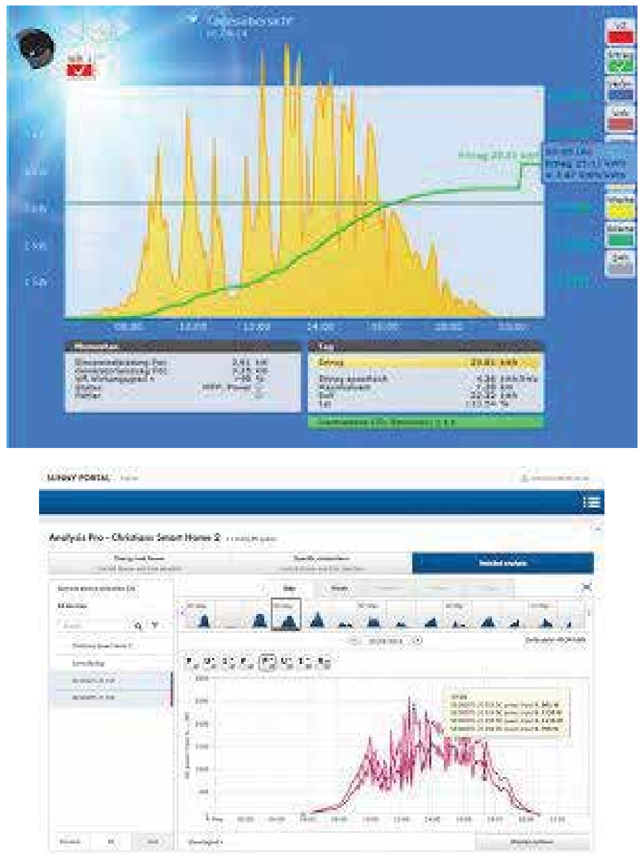


Figure 190: Visualization and analysis of a solar power systems

For standard solar systems, various monitoring devices and web-based software are available. They include a report function on the achieved solar yield and error reporting in case of any malfunctions of the system. The software allows a thorough analysis of the operation and comparison of achieved savings according to calculated figures (figure 190).

Special solar systems, such as hybrid or off-grid applications, also require the following devices, in addition to the control and monitoring system:

a) Charge control for batteries

If batteries are included in the solar power system, an additional hardware control device is necessary to control the charging/discharging of the batteries (figure 191). Usually, the inverter and battery supplier provide the control device. The charge control ensures that the batteries are optimally charged/discharged to protect them from deep discharges (i.e. over discharging), which negatively affects the battery's lifecycle. Lastly, it is important that the charge control fits the used battery technology.

b) Switch control for hybrid systems with switch operation

In a hybrid system with a switch operation the switch control changes between 100% solar operation to 100% generator operation. It is in charge for exchanging between the two systems, whenever solar irradiation is insufficient to satisfy the demand profile.

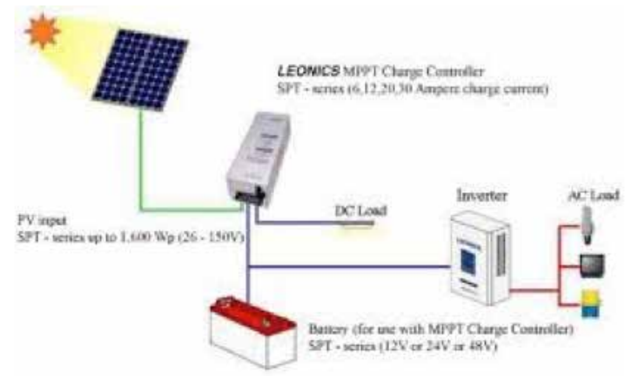


Figure 191: Charge control for batteries in a solar power system

c) Power and consumer management for hybrid systems (i.e. fuel saver solutions)

In a fuel saver system, solar energy and generators operate in parallel. They usually require a special control system that balances the use of the two power sources, especially in system designs where the solar fraction exceeds 20-30% and the internal control of the generator is insufficient to react to fluctuations in solar energy and demand. The power management of the control meter reduces the solar output, whenever the power demand of the generator drops to a minimum level in which it loses efficiency and its consequences would shorten the lifetime of the generator. The control meters (i.e. fuel saver control) records relevant data in the system, such as solar power, demand profile and generator load. It manages the power generation to ensure best performance and avoid conflicts between the two sources. Additionally to the power management of the solar system, the control meter also manages the consumer output, in which it enables/disables the operation of consumers, depending on the actual load and power supply.

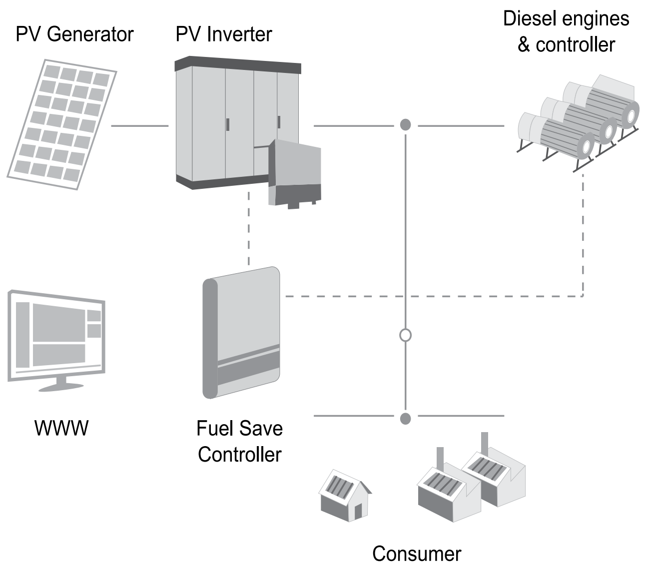


Figure 193: Switch control for hybrid systems with switch operation

Functions of a fuel saver control:

- Power management for the solar power system
- Consumer management for the connected consumers
- Operation management of the connected generator sets

Figure 194: Grid and system protection with monitoring relay and motor switches

d) Grid and system protection

A grid and system protection is always recommended for larger solar power systems and is often required by the public utility (figure 194). The control consists of a monitoring relay that continuously observes voltage and frequency of the grid. In case of any disturbances, two motor switches are activated by the relay and disconnect the solar system safely from the grid. Once all parameters are in an acceptable range, the solar system is reconnected to the grid.

Batteries for solar power systems

Batteries can be used in solar power systems to increase the solar operating time and the efficiency of the system. The inclusion of batteries is an option for grid-connected, self-consumption or hybrid system, in which the batteries are charged and used with the help of a switch control. In fact, for off-grid applications batteries have to be included, whenever the system is not operating on a pure switch operation.

Smaller battery banks can be used to store solar excess during peak sunshine hours. The stored energy is then used during insufficient solar irradiation during the day (e.g. clouds). The batteries smooth the daytime operations, whilst increasing the solar operating time and eliminating any solar energy waste at peak sunshine hours. Further, batteries are also useful to balance short-term fluctuations in power supply and demand. In this case, the battery capacity can be smaller and costs are lower. The batteries do not influence the size of the solar system, but are rather used to buffer any excess solar capacity.

Figure 195: Grid and system protection with monitoring relay and motor switches

Another option is to design the batteries according to the time gap between the possible solar operating time and the required operating time. The battery bank has to be sized according to the expected demand profile and operating time, whereas the solar system has to be oversized in order to charge the batteries during sunshine hours, whilst satisfying the daytime demand.

Batteries for solar energy storage are designed to outlast numerous discharge/charge cycles and are capable of deep-cycles. The batteries are discharged to 50-80% of their capacity on a regular basis before being recharged again. Therefore, the actual battery capacity depends on the degree of discharge (DoD), rather than the nominal battery capacity, and is therefore a key factor when choosing the suitable battery for the solar system. The DoD under operation is usually in a range between 50-70%. In case of a 50% DoD, the nominal size of the batteries needs to be doubled to serve the required capacity of the solar system. Thus, the design of the battery bank has to be decided based on the DoD, the battery technology, the assumed operating conditions and the expected lifetime of the batteries. As a general rule, the higher the DoD, the shorter the lifetime. In solar power systems, it is very important that the batteries are suitable for the environmental conditions, especially if the application is located in desert or coastal areas. Battery efficiency and lifetime depend strongly on operating temperatures.

EXAMPLE 28

Battery bank

Power demand: 75 kW
Expected operating time based on batteries: 10 h
Battery efficiency: 90%
Required energy: 75 kW×10 h/0.9 = 833 kWh
→ Useful capacity
DoD designed 50%

Required nominal capacity of battery bank:
1,670 kWh

For all solar power systems with batteries, it is essential to design according to accurate demand figures to reach an integrated design concept. Any over- or under-sizing will always have a negative impact on costs, reliability and lifetime of the system. The market for batteries is currently strongly developing with lifetime and capacities improving at decreasing prices. The following information can assist in getting a basic understanding of available battery technologies. However it does not represent the entire product range available on the market. It is strongly recommended to include specialists from an experienced system provider or manufacturer at the design phase during the feasibility study of the project.

Battery Technologies:

Lead-acid batteries (LA) are one of the most cost-effective solutions. It is a mature technology with an improved design well suitable for solar power systems.

Figure 196: Lead-acid batteries (LA)

Within the lead-acid category there are two main types: (1) Flooded and (2) sealed batteries. (1) The flooded batteries are the least expensive battery option, but require regular check-ups to ensure electrolyte levels are maintained. Further, they must be vented properly, as during charging explosive gasses are produced. (2) Sealed absorbed glass mat (AGM) batteries and gel electrolyte (GEL) batteries require no watering or special venting.

Figure 197: Nickel-Metalhydrate (Ni-MH)

- Best choice for low-cost systems
- Widely available

Nickel-Metalhydrate (Ni-MH) batteries have a longer lifetime in systems with daily charge/discharge cycles. Their energy density is not as high as Li-Ion batteries, but their capacity is larger compared to standard lead-acid batteries. It is a mature technology and Ni-MH cells are available in a wide product variety. Further, Ni-MH batteries do not contain any flammable electrolytes.

Figure 198: Nickel-cadmium (Ni-Cad)

- Expensive
- Suitable for small scale applications

Nickel-cadmium (Ni-Cad) batteries are more expensive compared to lead-acid batteries. Their disposal is also costly due to their toxic cadmium content. Ni-Cad batteries require careful discharging patterns because of a possible chemical 'memory effect'. However, they are an excellent choice for solar power systems at locations of lower temperatures. Their main disadvantage is a their lower efficiency compared to other battery technologies.

Figure 199: Lithium-ion (Li-ion)

- Very expensive
- Lower efficiency

Lithium-ion (Li-ion) batteries are gaining popularity in both small off-grid applications and larger industrial solar systems. They are more expensive than NiCd batteries, but have a higher energy density and a lower self-discharging rate. Li-ion batteries have the same capacity of lead-acid batteries, but at 20% of the weight. They are sensitive to overheating and have a fire risk ('thermal runaway').

Figure 200: Nickel Iron (Ni-Fe)

- Expensive
- Require special control electronics
- Not suitable for high ambient temperatures

Nickel Iron (Ni-Fe) batteries have alkaline electric cells and are designed according to the original "Edison Cell". They provide a very long lifetime, but suffer high losses at frequent charging/discharging, which adds to the size of the solar system.

- High initial investment
- Long lifetime
- Low lifecycle costs

Comparison of battery performance:

Table 10: Comparison of battery characteristics

Technol-ogy	Category	Tempera-ture sensi-tivy	Environ-mental concern	Energy density	Efficiency (%)	Useful depth of discharge	Life span	Self dis-charge
Lead acid	Robust	(°C)	Gasing (H2), acid, toxic Pb	(W/kg)	60 to 70%	(%)	(cycles)	(% / month)
(LA)	Very robust	–10/+50°C Requires hydration	Toxic Pb	700	60 to 70%	50	400 - 800	5
Sealed LA	Very robust	–10/+50°C	Toxic Cd	700	80%	50	600 - 1200	5
(VRLA, GM, GEL)	Robust	–30/+60°C	None	1000	85%	80	1500 - 2000	Over 20
Ni-Cad	Sensitive	–20/+50°C	Fire hazard	900	>90%	80	800- 1000	Over 30
(Nick-el-Cadmi-um)	Robust	-10/+45°C	None	1500	95%	80	500- 1000	2
Ni-MH (Nick-el-Metalhy-drate)	Very robust	Must not over-temp	Gassing (H2)	800	>90%	80	2000	5
Li-Ion (Lith-ium-Ion)		–20/+60°C		55		Over 90	n/a	20
Li-PO4 (Lithium Phosphate)		–20/+45°C Requires hydration						
Ni-Fe								

Battery lifetime:

- The lifetime of a battery depends on many factors. Likely causes of premature failure are:
- Drawing more current than the battery was designed for
- Over-discharging on regular basis
- Over-charging due to improper voltage setting
- Allowing electrolyte level in flooded cells to fall below plate level
- Topping up with other than distilled or DM water
- Operating or storing the battery in too high or too low ambient temperatures
- Subjecting the battery to excessive vibration or shock
- Excessive discharging in operation

Essentials for batteries:

- Long lifetime
- High number of cycles at high level of discharge
- Low maintenance
- Suitable for operations under high ambient temperatures
- Sizing based on operation conditions and DoD depending on expected lifetime.

Special requirements for systems with batteries in the MENA-region:

- High ambient temperatures
- Withstand sea-climate conditions if installed along the coast
- Check availability of spare batteries for exchange

4.3. INSTALLATION OF SOLAR POWER SYSTEMS

4.3.1 SYSTEM INSTALLATION

The installation of the mounting structure and PV panels can be mostly done with the help of workers without specific experience in solar systems. However, the installation requires the supervision of a solar specialist to ensure correct execution. Regarding the DC wiring and inverter setup, professional solar energy installers are needed. They should be well schooled and experienced, as the solar arrays are under high DC voltage and therefore special attention has to be given when installing the wiring and inverters.

Installation steps of a solar power system:

1. Check of preconditions
2. Safety check
3. Installation of mounting structure
4. Placement of inverters and AC connection unit
5. DC wiring
6. Installation of panels
7. AC wiring
8. Batteries (if applicable)
9. Generator (if applicable)
10. Metering and control
11. Start-up and functional tests

CAUTION: Sun protection and sufficient water supply for the installers is a must, when installing a solar power system. Installations are under constant sun exposure and require high physical effort.

4.3.2. GUIDE VALUES FOR INSTALLATION TIMES

Installation times differ for each project depending on the weather conditions at the site and system size. As a general rule of thumb, the installation of a system with up to 200 kWp requires approx. 2 weeks. This is due to the fact that some steps during the installation process are necessary for all types of systems regardless of its size and type. These include the metering and control functions, the AC connection and starting up the system. The time needed for the installation of the support structure and panels can be similar for small and larger projects, if the amount of worker is increasing proportionally to the system size. If a system reaches a size of 500 kW or above, the time for the installation can be optimized by a more structured organization and executing several steps in parallel.

The following daily itinerary can give an estimation of the steps and time requirements of a rooftop installation of 200 kWp based on the experience from realized projects:

DAY 1: PRECONDITIONS AND SAFETY CHECKS

During the first day, any preconditions and safety matters on the roof prior to the installation have to be verified. Measures on the required installation areas have to be marked. The preconditions should include a check on all materials and tools available on site and whether the work environment and weather conditions on the site are as expected. The locations for the installation of PV modules, inverters, AC connection units and batteries and/or generators should be verified.

201: Personal safety equipment with a lifeline and a safety net, surrounding the installation area.

The safety precautions must include the safety of the working area. Safety measures include safety nets or lifelines during roof top installations and well accessible transport options for the equipment (figure 201). It is recommended to make a health and safety plan to include all risks on site and protection measures. This should not only include fall hazards, but also other important safety measures, such as preventative actions against explosives in the working area. The first day of the installation is used for any preconditions and safety checks at the project's site and usually requires 3 workers and a professional and experienced supervisor.

DAY 2: BASELINE FOR THE SUPPORT STRUCTURE

During the second installation day, all necessary material for the baseline of the support structure has to be transported onto the roof via a crane (figure 202). The baseline is the first or last row of the support profile at the installation area (figure 203). It has to be placed accurately, as all further profiles will be adjusted accordingly. The baseline is the decisive factor for a rectangular installation and it avoids later conflicts, when installing the panels. It is strongly recommended to use horizontal and vertical lines as orientation for the installers. Further, it is advised to use appropriate tools to ensure equal distances between different rows.

The second day is more time consuming and requires around 10 workers, 2 specialists and if no crane is available, additional 6-10 workers to support the transport of the materials onto the roof.

Figure 202: Crane for lifting the installation materials

Figure 203: Baseline for the support structure

Figure 204: Support structure installation with lines to mark the edges of the profiles and tools for distance control

DAY 3-5: COMPLETE SUPPORT STRUCTURE

It takes 3 days to finalise the installation of the support structure with the help of 10 workers and a professional and experienced solar system specialist.

- Accuracy is key when installing the support structure, as mistakes have a direct negative impact on the installation of the PV modules and the final outlook of the system on the roof
- Integration into the lightning protection concept has to be checked
- The support structure must be grounded

Figure 205: Frequent installation check-ups

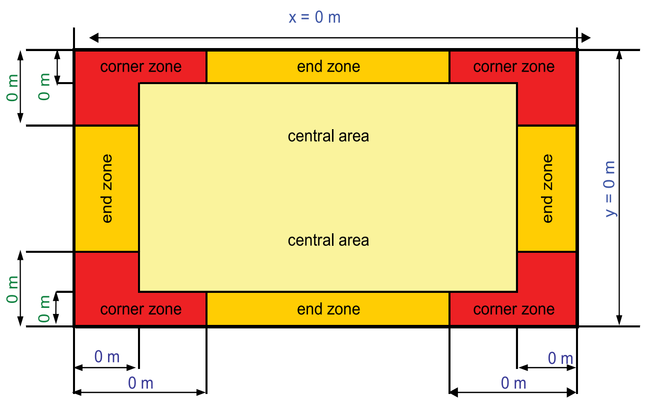


Figure 206: Different zones of a module area with different fixation or ballasting

IMPORTANT: Accurate work, frequent check ups and measurements as well as suitable tools are important for installing the support structure.

- Set the solar fasteners or ballasting for fixing to the static calculation of the support structure
- Different zones require different quantity of fasteners or ballasting due to wind load distribution
- Corners and end zones have the highest density

Figure 207: Placement of inverters

In parallel to the support structure, a specialist at the site can place the inverters and AC connection units with the help of 1 worker. The installation of the inverters can be done inside or outside, if the protection class of the inverter allows. In case of an outside installation, it is important to choose a place, where the exposure to dust and sand can be minimized. The inverters must be protected from direct sunlight, which can be done via a small roof or cabin installation (figure 208). Further, during the installation of the inverters, the minimum distances for efficient ventilation and cooling of the inverters and maximum ambient temperatures of operation have to be considered, according to the installation manual of the supplier. In general, it is always better for the system and the inverter efficiency to have the ambient temperature during operation as low as possible. As a general rule, the higher the ambient temperature, the lower the efficiency of the solar system and its inverters.

Figure 208: Inverter installation under a solar panel roof for shading

Also the AC connection unit can be placed outside, whenever it can be ensured that it is not directly exposed to sunlight and the maximum ambient temperature does not exceed the maximum possible temperatures for operation. The protection class of the unit has to be suitable for outside installations. Especially for larger systems, it is recommended to install the AC connection unit close to the final AC connection on the grid, inside the building in a room with moderate temperatures (figure 209)

Figure 209: Installation of an AC connection unit

DAY 6: STRING BOX INSTALLATION

On day 6, the string boxes and DC string wiring can be installed with the help of 2 workers and 2 solar system specialists.

- Do not close the strings in the module area, before they are connected to the string boxes or inverters. Add connectors to all wiring and leave <+> or <-> plug disconnected in each string.
- Only use qualified and certified DC wiring and connectors for solar power installations
- Never connect DC wiring by twisting and taping the wires
- Attention to the DC system voltage (up to 1500V)
- Only use qualified, double shielded wires
- Wires' maximum voltage has to be larger than the system voltage!

Figure 210: High DC voltage in the string wiring, if wire endings are free and strings are connected.

CAUTION: Panels are under DC voltage when exposed to sunshine. Open wires can cause serious danger.

In case DC string combiner boxes are required according to the system design, they should be installed in a shaded area to avoid any direct sunshine (figure 211). Depending on the protection class of the string combiner boxes, the installation can be inside the building or outside close to the module area to keep DC strings as short as possible and reduce losses due to DC wiring. To minimize losses, the main DC wire starting from the combiner boxes to the inverters must be sized accurately.

Lead wires of <+> and <-> for each string from DC combiner box or inverters to the string position within the array and install a solar connector, such as Phönix Contact or Multi-Contact. Keep the wire connector for later connections with PV panels.

Figure 211: Installation of DC string combiner boxes

- Accurate and correct marking of DC wires for the individual strings is essential
- Incomplete or incorrect marking and connection may cause wrong polarity of strings, resulting in difficulties at the next installation step
- Use labels or permanent (white) marker

In parallel to the installation of the string boxes and lead wires, cable ducts and protection pipes can be assembled with the help of 1 solar system specialist and 3 to 4 workers. The DC and AC wiring should be covered with cable ducts or protection pipes to protect the wires from external influences. Cable protection is necessary to avoid any exposure to UV-radiation, animal picking, rain and other environmental influences, especially for outside cables.

- Cable ducts have to be of anti-corrosive material or protected against corrosion via long-term protection paint
- Cable ducts and protection pipes must be assembled without any gaps in between to ensure that all wiring is protected from external influences at all times

Figure 212: Prepare DC wiring within the module area and solar connector with appropriate crimping tools.

DAY 7 TO 10: PV MODULE INSTALLATION

It takes approx. 4 days to install the PV modules onto the support structure and connect the strings of each module to one another. Start the assembly of the PV panels from either the first or last row of the baseline profile and use lines to ensure accurate placement of the panels in a straight line. The installation usually requires 2 solar system specialists and 10 to 12 workers.

- Make sure that all mdules are connected with PV connectors on the panels within the module area during installation.
- Make sure that all module clamps are fixed tightly according to the requirements of the supplier.
- Fix the connectors with cable strings to the supppert structure to avoid any connectors lying on the roof that could be soaked in water during rain
- Connect string by string and check voltage and polarity when connected

Figure 213: Cable duct for DC wiring on the roof and AC wiring at the inverter

During day 7 and 10, also prepare the data wiring with the help of 1 solar system specialist and 1 worker. For the data wiring, the Bus-connections (e.g. RS485 or Ethernet) have to be installed, according to the system design and component requirements.

- For data wiring suitabe wires, such as CAT 7 or CAT 5 should be used to ensure operations without conflicts
- Manuals and datasheets of components have to be considered prior to installation

For the data wiring the following preparations have to be taken:

- Internet connection for online access and monitoring
- Data wiring from inverters to control unit (e.g SolarLog or SMA Cluster Control)
- Data wiring for sensors include irradiation, wind and temperatures
- Data wiring for metering solar power and demand
- Data wiring for other control devices (e.g. charge control, generator, etc.)

Figure 214: Assembly of PV panels

DAY 11 AND 12: FINALISE AC WIRING AND INSTALL CONTROL AND METERING DEVICES

During day 11 and 12, it should be possible to finalise all AC wiring and connecting them to the distribution board with the help of 2 solar system specialists and 3 to 4 workers. Parallel to the AC wiring, the control and metering devices can be installed by 1 specialist and 1 worker.

- Check manual of inverters carefully
- Make sure that inverters are set correctly to the country and grid parameters before energizing the system
- Check IT settings and install necessary software for control and monitoring
- Document IT and control settings

Figure 215: Installation of solar panels

Figure 216: Data wiring of inverters and control device (SolarLog)

Figure 217: Sensors in a solar power system

Figure 218: Installed AC connection unit

DAY 13 AND 14: START-UP AND TESTING

The last two installation days are needed for the solar system start-up and testing. It is recommended to follow official test protocols, for instance from the German Solar Industry Association (BSW).

The start-up of the solar system includes:

- Energize the system and check for stable power generation
- Physical check of installation
- Adjust power factor at the solar control (if necessary)
- String protocol using qualified tool (e.g. Benning PV1)
- Functional tests for:
  - Power generation
  - Grid and system protection
  - Power management (if included)
  - Grounding resistances
  - Hybrid operation with switch or fuel save control
  - Battery charging and discharging

Figure 219: Solar tester to create a start-up and string protocol

Table 11: String protocol

Inverter					Module		Benning PV 1-1 Serial no 48F-0214						
Number	Type	Ser. Nr.:	String	Input	qty.	Wp	Index	Voc (VDC)	Isc (ADC)	Riso (MOhm)	Viso (V)	HH:MM:SS	DD/MM/YYYY
1	Tripower 2500 TL	1900743059	1.1	A1	22	260	1	742	5.24	>199	500	08:51:51	20.04.16
			1.2	A2	22		2	738	5.61	>199	500	08:52:12	20.04.16
			1.3	A3	22		3	735	5.69	>199	500	08:52:42	20.04.16
			1.4	B1	21		4	695	5.64	>199	500	08:53:42	20.04.16
			1.5	B2	21		5	693	5.67	>199	500	08:53:58	20.04.16
2	Tripower 2500 TL	1900742823	2.1	A1	22	260	6	728	7.49	>199	500	08:06:49	21.04.16
			2.2	A2	22		7	728	7.48	>199	500	08:07:12	21.04.16
			2.3	A3	22		8	731	7.45	>199	500	08:07:44	21.04.16
			2.4	B1	21		9	687	7.47	>199	500	08:08:00	21.04.16
			2.5	B2	21		10	688	7.51	>199	500	08:08:22	21.04.16
3	Tripower 2500 TL	1900742974	3.1	A1	22	260	11	737	7.32	>199	500	08:08:56	21.04.16
			3.2	A2	22		12	722	7.31	>199	500	08:09:13	21.04.16
			3.3	A3	22		13	718	7.29	>199	500	08:09:34	21.04.16
			3.4	B1	21		14	687	7.32	>199	500	08:09:50	21.04.16
			3.5	B2	21		15	685	7.32	>199	500	08:10:06	21.04.16
4	Tripower 2500 TL	190074256	4.1	A1	22	260	16	724	7.29	>199	500	08:10:30	21.04.16
			4.2	A2	22		17	716	7.29	>199	500	08:10:46	21.04.16
			4.3	A3	22		18	718	7.31	>199	500	08:10:58	21.04.16
			4.4	B1	21		19	683	7.31	>199	500	08:11:21	21.04.16
			4.5	B2	21		20	689	7.39	>199	500	08:11:35	21.04.16
5	Tripower 2500 TL	1900742648	5.1	A1	14	260	21	464	7.01	>199	500	08:12:18	21.04.16
			5.2	A2	14		22	459	7.12	>199	500	08:12:38	21.04.16
			5.3	A3	14		23	460	7.03	>199	500	08:12:53	21.04.16
			5.4	A4	14		24	459	7.12	>199	500	08:13:08	21.04.16
			5.5	B1	21		25	693	7.36	>199	500	08:13:25	21.04.16
			5.6	B2	21		26	691	7.38	>199	500	08:13:40	21.04.16
6	Tripower 2500 TL	1900743014	6.1	A1	20	260	27	667	7.09	>199	500	08:14:41	21.04.16
			6.2	A2	20		28	660	7.02	>199	500	08:15:09	21.04.16
			6.3	A3	20		29	665	7.06	>199	500	08:15:28	21.04.16
			6.4	B1	15		30	498	7.33	>199	500	08:17:55	21.04.16
			6.5	B2	15		31	495	7.29	>199	500	08:19:26	21.04.16
			6.6	B3	15		32	492	7.34	>199	500	08:19:51	21.04.16

Table 12: Start-up protocol in accordance with German Solar Industry Association (BSW) - 1

Acceptance Report Solar Power System

Common Informations

Plant Operator / Customer	**Plant Acceptor / Company**
Last name, first name	Last name, first name
Street, number	Street, number
Zip code, place	Zip code, place
Tel. (private, business, mobile)	Tel. (private, business, mobile)
Fax	Fax
E-mail	E-mail

Technical Plant Data

Plant document is available completely:

☐ yes Remark: ______________________________

☐ no

Generator capacity (P_{PV}): ______ kWp

Modules (manufacturer, type, quantity): ______________________________

Inverters
(manufacturer, type, quantity, capacity AC): ______________________________

☐ see attachment

Table 13: Start-up protocol in accordance with German Solar Industry Association (BSW) - 2

Acceptance Report – PV Plant **Project** ______________________

Quantity of the strings per inverter,
quantity of the modules per string: ______________________

☐ see attachment

External lightning protection available?

☐ yes Remark: ______________________

☐ no

☐ see attachment

Overvoltage protection AC side (if available)
(manufacturer, type, nominal voltage): ______________________

Overvoltage protection DC side (if available)
(manufacturer, type, nominal voltage): ______________________

Potential equalization / grounding:

☐ yes Execution, place of installation, remark: ______________________

☐ no

Function, yield, data (remote) monitoring available?

☐ yes

☐ no

If available, manufacturer, type, quantity to be measured and analysed: ______________________

Person/company, in charge of the function, yield, data (remote) monitoring: ______________________

Grounding resistance of the grounding unit in ohm: ______ Ω

Date of the measure: ______________________

Isolation resistance of the PV generator: ______ MΩ (+/- 0.5 MΩ)

Other remarks: ______________________

Table 14: Start-up protocol in accordance with German Solar Industry Association (BSW) - 3

Acceptance Report – PV Plant **Project** ______________________

Visual Inspections, Matching with the Planning

(please cancel, if not applicable)

Plant assembly without apparent damages at the plant, roof, building etc.	in order / rejected
Roof permeations / sealings	in order / rejected
Assembly system / arrangement of the wiring	in order / rejected
Inverters, inverter function	in order / rejected
Feed-in control at the meter	in order / rejected
Function, yield, data (remote) monitoring (if available)	in order / rejected
Plant fully functional	in order / rejected

Customer Briefing

A briefing for the plant operator / customer has occured:

☐ yes

☐ no

Other remarks: ______________________

Other Remarks:

Possible rectifications to be executed, have to be listed incl. the execution period:

Table 15: Start-up protocol in accordance with German Solar Industry Association (BSW) - 4

Acceptance Report – PV Plant **Project**

Documentation

The complete documentation was delivered to the plant operator / customer respectively deposited on an appropriate place (technical room of the inverters, nearby the meter cabinet:

- ☐ Technical documents and data sheets of all used components
- ☐ Certificates
- ☐ Warranty certifications
- ☐ String plan and roof plan with module connection and allocation of the modules
- ☐ Manual, particularly of the inverters
- ☐ If applicable, manual of the function, yield, data (remote) monitoring
- ☐ Assembly manuals of used components
- ☐ Service respectively emergency phone numbers

Other remarks: ______________________

The documents have to be added with date respectively should be stamped and initialised.

By signing this Acceptance Report, the plant is applied for the acceptance.

____
Place, date

______________________ ______________________
Signature of the Plant Operator / Customer — Signature of the Plant Acceptor / Company

Attachment

Figure 220: Finished solar power system

- Consumer management if implemented
- Online monitoring and control
- System handover to operators
- Train operators on how to use and maintain the system
- Handover of documentation

When installing batteries and/or generators, the technical information of the supplier must be included into the installation time frame, as steps and time efforts are different and depend on the system concept and technology chosen.

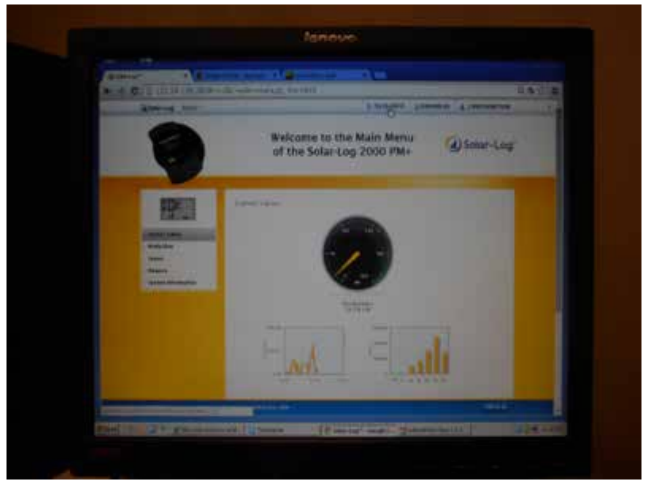


Figure 221: Operational control via local control software

4.3.3. OPERATING A SOLAR POWER SYSTEM

During normal operation, no change of settings, operator or any other interaction of the system is required. It is only necessary to follow the maintenance schedule accurately and to observe the system for any malfunctions, indicated by the solar control or the monitoring system.

- Observe and control the module area on the roof regularly
- Try to identify any defects in wiring or mechanics, as early as possible

Regular control and attendance of the system

The operator is responsible for the correct operation of the safety devices and regular inspection of the system, regarding any external identifiable damages. Additionally, the system has to be inspected for failures at the solar control or monitoring system on a regular basis. In case of any malfunctions, the time between the detection and fault clearance is in the responsibility of the system operator.

The operator is responsible for:

- Normal system operations
- Restricted operations with special adjusted warning notices and instructions, with reference to the difficulties
- Shut down

Predictable break in operation

During predictable break periods without any power demand (e.g. maintenance, longer holiday) of more than one week, it is recommended to completely shut down the solar system.

4.3.4. MAINTENANCE OF A SOLAR POWER SYSTEM

4.3.4.1. REGULAR MAINTENANCE

The regular maintenance for solar power systems is primarily limited to the following tasks:

- Cleaning module area
- Check system for damage
- Check system performance
- Check protective devices
- Keep system in good condition

Maintenance Tasks

1. Keep system in a good shape

The main responsibility of the system operator is to keep the system in good shape. Its condition has an important influence on the efficiency and therefore possible energy savings. Defects or smaller mechanical damages should be repaired immediately, to keep the whole system operating optimally at a high efficiency over its entire lifetime.

2. Monitoring of operation

The software tools of the inverters or additional control and data logging devices allow permanent monitoring of the operation. This includes efficiency and solar yield control, which enables the comparison of the actual data to the design. In case of larger systems, the observation of single strings is also possible. Messages via Email or SMS can be implemented to inform the operator about the performance.

3. Check module area

It is possible that damages of the solar system occur during its lifetime that are caused by mistakes at installation, continuous tension or vibration, mechanical damage or any maltreatment during the maintenance of the system.

To keep the system operational:

- Check for damages regularly
- Visible control along wiring and module area
- Loose connections are solved via tightening the joints
- Defect parts have to be repaired or replaced
- Damage indicators:
- Loose modules
- Visible damage at support structure or cable ducts

Table 14: Example of a maintenance schedule for a solar power system

aschoff solar

Solar Power System - Maintenance Schedule

Project: DBW | Customer: DBW Vietnam | Location: Ho Chi Minh City
Contract: | Start of Operation:

task	freq.	tool / ref
A) Monitoring of Operation		
remote monitoring of operation	daily	web portal
observe strings and inverters	daily	web portal
check error messages	daily	web portal
B) Module Area		
check of module surface	quarterly	visual
check of module frames	quarterly	visual
check of support structure	quarterly	visual
check of DC wiring	quarterly	visual
cleaning of module area	on demand	water/brush
C) Inverters		
inspection of inverters	quarterly	visual
checking the fans	half year	manual SMC
cleaning the fans	on demand	soft brush
cleaning the ventilation grids	on demand	soft brush
checking the ESS	yearly	manual SMC
E) AC Disconnection Box		
check connection AC box	yearly	visual
check settings of ESS relay	yearly	visual
check self test ESS relay	quarterly	manual ESS
check motor switches	yearly	functional
F) Data Logging System		
check Solar Log	quarterly	web portal
check SmartFox	quarterly	display
General Inspection		

week of operation: 1 – 52

Aschoff Solar | Terramar | Customer

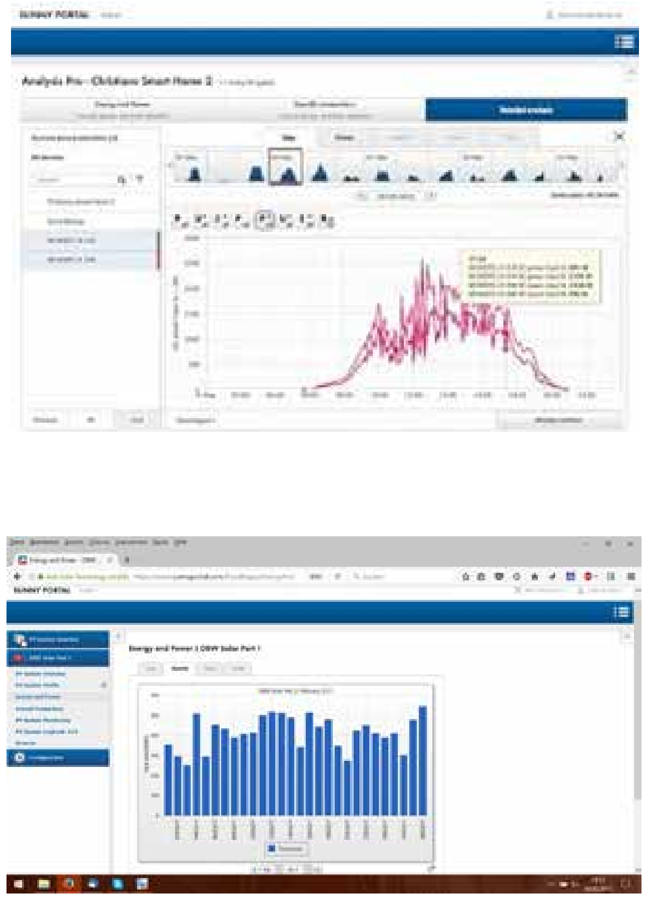


Figure 222: Online monitoring via SMA web portal and Email message for daily performance control

4. Check support structure

The support structure has to withstand the environmental conditions at the project site for a lifetime of at least 20-25 years. Therefore, it is necessary to check for any mechanical damage and corrosion. Be aware that external influences, such as wind or vibrations, can have an impact on screwed connections, which need to be checked on a regular basis to ensure the stability of the system.

To keep a stable support structure:

- Check the support structure regularly
- Visible control along the module area and wiring
- Identified damages have to be repaired
- Corroded parts have to be replaced or cleaned and protected against further corrosion

Damage indicators:

- Corrosion at steel or stainless steel parts
- Loss of material due to corrosion
- Loose parts in the support structure
- Ballasting removed from initial position

5. DC wiring

The DC wiring has to be accurately covered in cable ducts, in order not to be damaged by any environmental influences, such as sunshine or animal picking. For safety and performance reasons, it is essential to keep the DC wiring in good condition.

To keep the DC wiring in good condition:

- Regular visual inspections along the DC wiring from inverters to string boxes and module area

Figure 223: Roof top support structures

Damage indicators:

- Porous wires
- Cracks in wires
- Open connectors
- Damaged wires

6. Cleaning the PV modules

It is crucial to clean the PV modules on a regular basis to ensure the full performance of the system. Dirt or other sediments on the module lower its efficiency, as it reduces the direct absorption of sun irradiation. The necessary cleaning frequency depends on the environmental conditions of the project's location.

To keep the system performance:

- Use fresh water or water mixed with domestic detergent or soap to clean the modules
- Do not use any chemicals that could influence the glass surface

CAUTION: Do not scratch the module surface

7. Inverter and charge control inspection (if applicable)

The inverters and charge controls are key components of the system. They are essential for the lifetime of the solar system, its operation and performance. Therefore, they need to be inspected on a regular basis.

To keep the inverters and controls well functioning:

- Consider the inverter and charge control manuals when inspecting
- Check and clean cooling devices (e.g. fans)
- Check integrated overvoltage protection (if included)
- Damage indicators:
- Dirty cooling fans
- Mechanical damage
- High temperatures
- Frequent shut down of inverters due to malfunction

8. Check AC connection unit

The inspection of the AC connection is an integral part of the maintenance of a solar system to ensure safe and stable solar operations.

To keep the AC connection intact:

- Regular visual check-ups of the AC connection unit for damages and dirt
- Check integrated fuses and overvoltage protection
- Self-test of grid and system protection according to manual of monitoring relay
- Test switch or fuel save control in case of hybrid systems

Damage indicators:

- Loose connections at the AC connection unit
- Released fuses and overvoltage protections (specific manual of supplier)
- Dirt in the cabinet

9. Batteries

The effort needed to maintain batteries depend on the battery technology and it supplier. It is not possible to give valid general suggestions on how to maintain batteries, except to keep batteries in a cool and ventilated environment to ensure best possible performance and lifetime.

10. Generators

The generators have to be maintained based on their technical manual.

4.3.5 DOS AND DON´TS

Dos

- Only use qualified and certified components for solar power systems that can ensure a long lifetime and operations over decades
- Always consider the specific location of the project and environmental conditions for the choice of components and installation materials (e.g. sandstorms, salinity, etc.)
- Employ at least 2 qualified supervisors during installation, in case the installation is done with the help of unqualified and/or inexperienced workers
- Measure roof or field prior to installation
- Arrange installation areas accurately, straight and rectangular, to avoid problems with further installation steps
- Disconnect inverters safely from AC grid prior to any maintenance work

Don'ts

- Don't install a support structure without wind load calculations and static system proof
- Don't use standard wires for DC wiring without approval to be used in solar power systems
- Don't install inverters, string boxes, charge controllers or batteries in areas with direct sun exposure
- Don't connect strings on the roof, if DC connection at inverters or string combiner boxes is not ready – 1000 V
- Don't work on the AC side of installation, if system is exposed to sunshine

SOLAR THERMAL IN DETAIL

05

Chapter Five

5.1 DESIGN AND SIZING OF SOLAR THERMAL SYSTEMS

5.1.1 BASIC DATA FOR SIZING

The size of the thermal collector field is designed according to the hot water demand of the hotel and the expected solar fraction. The solar fraction is the portion of energy demand that is provided by the solar system. The remaining energy of the demand profile is handled by a conventional heating system. In the tourism sector, the solar fraction rates of economic solar systems for hot water are between 40 and 70%. The best way to collect the data to size the system is to fill out a standard questionnaire (i.e. planning sheet) for the project (picture 169). The questionnaire is in most cases sent by the supplier of the thermal system.

The size the system accurately the following data is needed:

- DHW[1] consumption / Number of persons
  - Data according to national standards e.g. DIN 1988, VDI, SIA, ASHRAE, etc.
  - See also chapter 4.1.3
- Tapping profile / Peak tapping / Circulation
  - Standard profile stored in simulation software (adaptable)
  - See also chapter 4.4
- Required DHW outlet temperatures
  - DHW following local rules, e.g. legionella regulation at 60 °C
- Required solar fraction
  - Customer / user demand
  - Solar fraction <> system efficiency
  - See also chapter 6.1.2
- Available space and orientation
  - Areas for collector field
  - Space for storage
  - Insertion openings
- Meteorological data
  - Location included in planning sheet
  - Climate data stored in simulation software
- Location / Local situation
  - Shadowing
  - Onsite visit
- Static data
  - Height of the building,
  - Wind load
  - Wind velocity

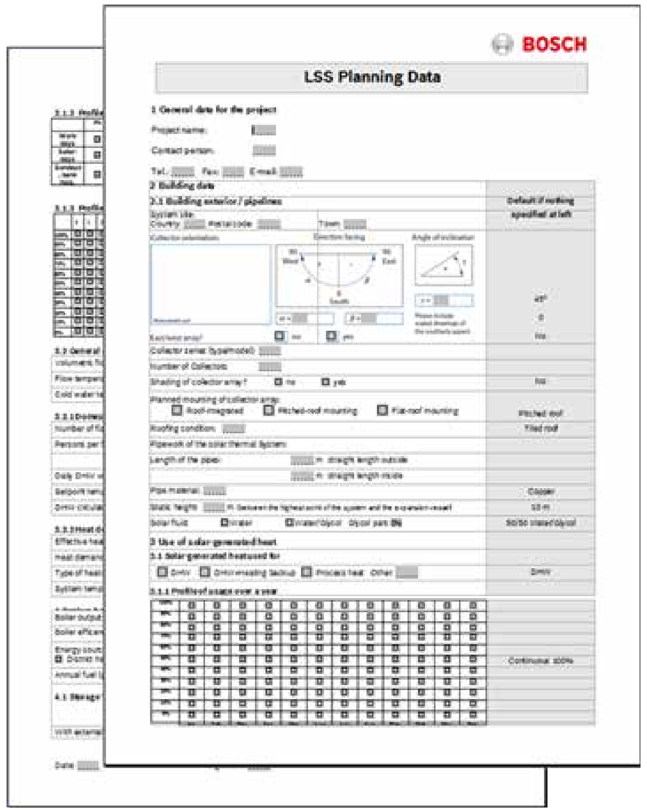

BOSCH
LSS Planning Data
1 General data for the project
Project name:
Contact person:
Tel.: Fax: E-mail:
2 Building data
2.1 Building exterior / pipelines
Default if nothing specified at left
3 Use of solar generated heat

Figure 224: Data collection with a planning sheet

5.1.2 PRINCIPLES OF SIZING

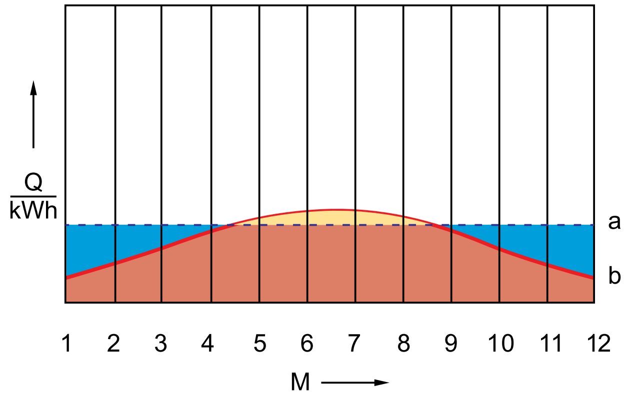
The size of the collector field depends on the heat demand during the summer months.

A hotel's heat demand consist of:

- Hot water demand
- Circulation heat demand
- Pool heating (if required)
  - The solar thermal system can only transfer heat when there is demand. The energy demand during the summer period of a pool in a hotel in the MENA-region is quite low. Often direct sun exposure heats the pool up to the needed level. Thus, no or less solar energy is needed for pool heating. It is best to size the system according to the demand during summer months, in order to avoid oversizing the system, which could lead to stagnation problems and inefficiency of the system.

[1] DHW = Domestic hot water

DHW[2] heating is the most common application for solar thermal systems and often the first step into the use of solar thermal. The DHW demand remains rather constant all yearlong, which works in favour of the solar energy yield. During the summer months, the energy demand for DHW heating can be covered by the solar thermal application, however during periods of bad weather, the conventional heating system must be able to satisfy the total DHW demand, independently of the solar heating-



a Energy demand
b Energy yield from solar thermal system
M Month
Q Heating energy
Excess solar energy (e.g. can be used for pool heating)
Solar energy used (solar coverage)
Energy demand not covered (reheating)

Figure 225: Energy yield of a solar collector system in relation to the annual energy demand for DHW

Specific solar yield (SY)

The specific solar yield is frequently specified as the main characteristic for the performance of solar thermal systems. It describes the annual energy amount, which is supplied from a square meter of collector surface area to energy storage (i.e. gross collector surface area).

Specific solar yield (SY) = QSolar/AGross surface area [kWh/m²xa]

QSolar = Annual heat generation of the solar power system in kWh (counted at secondary side of the solar circuit)

AGross surface area = Gross collector surface area in m²

EXAMPLE 29

Specific solar yield

For a solar system of a 150 m² collector field in a hotel in Cairo at a yearly irradiation of 1996 kWh/a onto the collector surface, the specific solar yield results in 1179 kWh/m² per collector.

Solar coverage SC (or solar fraction) versus system efficiency

The solar coverage value for a solar thermal system describes the solar fraction of the energy production. The following equation describes how to calculate the solar coverage.

$$\text{Solar coverage SC} = \frac{Q_{Solar}r}{Q_{Conv\ HI} + Q_{Solar}} (\%)$$

EQUATION 9:

QSolar = Annual heat input of the solar thermal system, measured on the secondary side of the solar circuit in kWh.

QConv HI = Annual heat input of the conventional heat generator, measured between energy storage and conventional heat generator in kWh.

The reference period can be calculated over any time period, but a yearly reference is recommended.

EXAMPLE 30

Solar coverage

For a solar system of a 150 m² collector field in a hotel in Cairo, the solar coverage of the DHW demand can reach up to 77% of the total hot water demand per year.

System utilization rate (SU)

The utilisation rate of a solar thermal system describes the relation between solar generation in energy storage and the energy on the collector surface. The utilization ratio is only one indicator for system efficiency and operation. It is the useful generated energy handed over to a consumer or stored compared to the energy collected by the collectors on the roof. The utilization ratio already includes piping and other thermal losses. Solar thermal systems of larger dimensions provide greater solar coverage, but less utilisation rates and vice versa. Systems with high solar coverage frequently operate on lower collector efficiency rates and are often not in operation during summer months. As a result, excess solar energy cannot be used and are therefore comparable with systems of lower coverage rates. The principle of the dependencies between the solar coverage rate (SC) and the solar utilisation rate (SU) are illustrated in figure 226.

[2] DHW = Domestic hot water

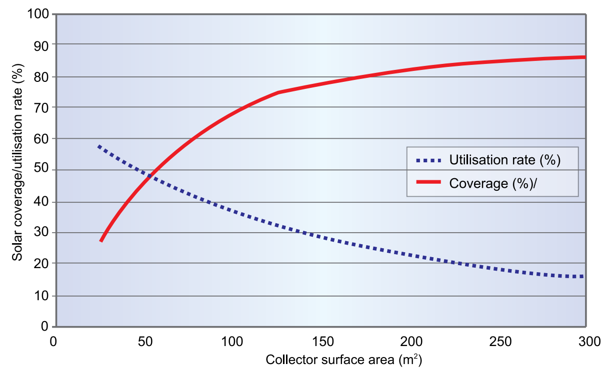


Figure 226: Solar coverage vs. utilisation (efficiency)

EXAMPLE 31

System coverage vs. utilisation

For a solar system of a 150m² collector field in a hotel in Cairo, the system efficiency can reach up to 58%.

5.1.3 SYSTEM SIZING

The following section includes a description of the sizing for 3 different system solutions, which were explained in detail in chapter 2, section 2.

These 3 systems are:

1. Solar Preheating with Serial Connection of DHW-boiler (PSC)
2. Fresh water system (FWS)
3. Preheat system (PHS)

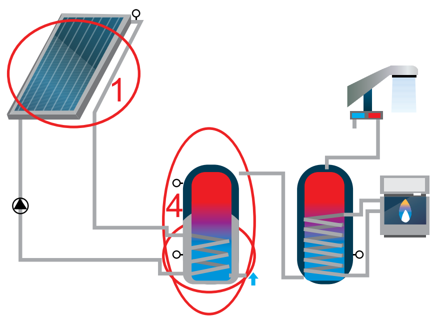


Figure 227: System 1

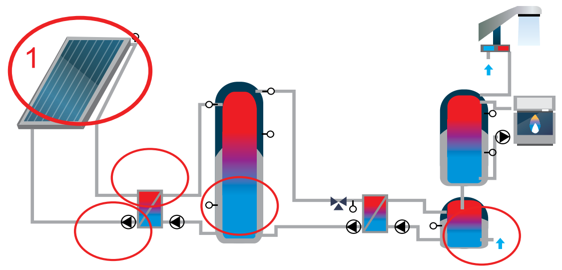


Figure 228: System 2

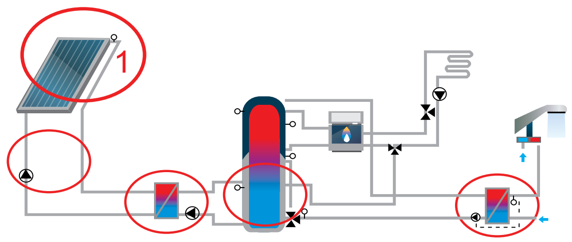


Figure 229: System 3

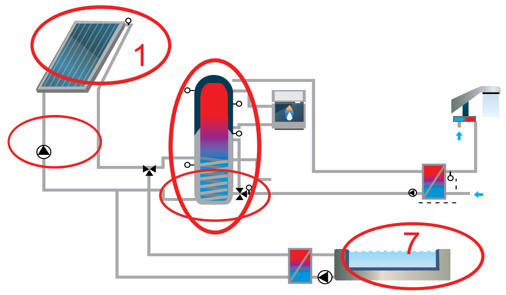


Figure 230: System 4

The main components that require sizing are:

1. The collector
2. The heat exchanger (internal or external)
3. Pump with safety components (e.g. expansion vessel)
4. Buffer tank or DHW tank
5. Preheat tank
6. Fresh water station
7. Pool heating

1. Sizing the collector array

The following table gives reference values for collector area and storage volume of solar thermal installations in the hotel sector, sized at an economical optimum.

Application	DHW (domestic hot water)
Solar coverage SC (solar fraction)	60-80%
Collector array	1m²/70-120 litre DHW per day

EXAMPLE 31

Sizing the collector array

A hotel has a daily consumption of 7000 litre per day. Location is Cairo.
7000 litre/70 litre/m² = 100m² collector array → Solar Coverage SC = 80%

A hotel has a daily consumption of 7000 litre per day. Location is Cairo.
7000 litre / 100 litre/m² = 70 m² collector array → Solar Coverage SC = 70%

A hotel has a daily consumption of 7000 litre per day. Location is Cairo.
7000 litre / 120 litre/m² = 58 m² collector array → Solar Coverage SC = 60%

Recommendation:

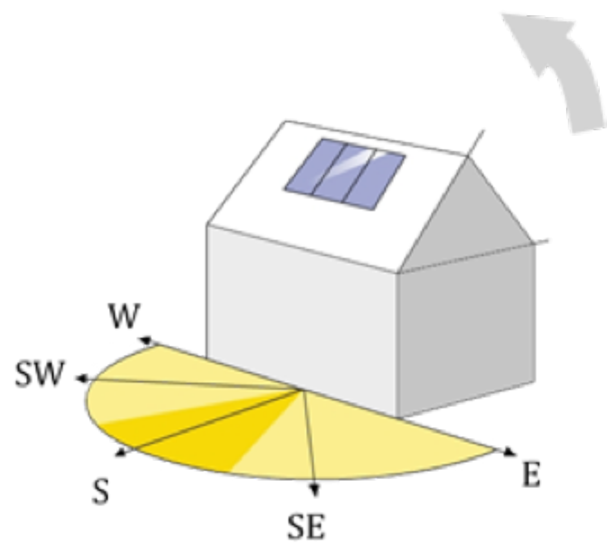


Figure 231: Collector field orientation

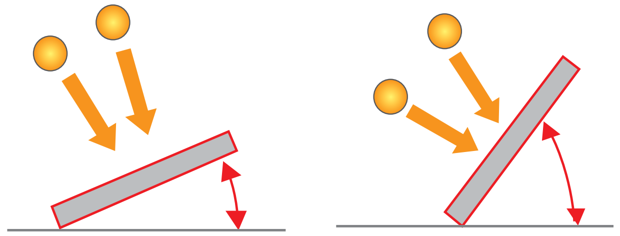


Figure 232: Winter position and summer position. 30° is often the best inclination for the MENA-region

As a general rule, the higher the reliability of the consumption data is, the higher the planned solar fraction. On average, 1m² collector array can heat up to 70 litre of DHW.

Inclination of the collector field

Please take into account the roof orientation and the roof pitch.

The ideal set-up angle of the collector is equal to the country's latitude. For the MENA-region a 30° inclination is the best compromise between the summer and winter position of the sun. If the orientation is to the west or east, the solar energy output is reduced.

In many cases, no orientation and inclination of the thermal collector need to be made if the collectors are not perfectly orientated to the south. All roofs between east and west are acceptable. In fact, between southeast and southwest no corrections are required. In case of sufficient space on the roof, small corrections of the collector fields area are beneficial.

Table 17: Correction factors for collector orientation deviation from the south for different inclination angles

Angle of inclination	Correction factors for collector orientation deviation from the south												
	Deviation to the west by						South	Deviation to the east by					
	90°	75°	60°	45°	30°	15°	0°	–15°	–30°	–45°	–60°	–75°	–90°
60°	1,26	1,19	1,13	1,09	1,06	1,05	1,05	1,06	1,09	1,13	1,19	1,26	1,34
55°	1,24	1,17	1,12	1,08	1,05	1,03	1,03	1,05	1,07	1,12	1,17	1,24	1,32
50°	1,23	1,16	1,1	1,06	1,03	1,02	1,01	1,04	1,06	1,1	1,16	1,22	1,3
45°	1,21	1,15	1,09	1,05	1,02	1,01	1	1,02	1,04	1,08	1,14	1,2	1,28
40°	1,2	1,14	1,09	1,05	1,02	1,01	1	1,02	1,04	1,08	1,13	1,19	1,26
35°	1,2	1,14	1,09	1,05	1,02	1,01	1,01	1,02	1,04	1,08	1,12	1,18	1,25
30°	1,19	1,14	1,09	1,06	1,03	1,02	1,01	1,03	1,05	1,08	1,13	1,18	1,24
25°	1,19	1,14	1,1	1,07	1,04	1,03	1,03	1,04	1,06	1,09	1,13	1,17	1,22

EXAMPLE 32

Collector orientation

As table 17 illustrates, if the orientation of the roof is faced 90° to the west and the inclination is at 40°, the collector array could be corrected by factor of 1.2. Thus, if the normal dimensioning of the collector array is 100m², it could be corrected to 100 m² × 1.2 = 120 m².

Recommendation:

The perfect condition to minimize the peak at 12 pm is to install the collector array on both roof sides (east and west).

2. Sizing the heat exchanger

The heat exchanger has to transfer the heat from the collector into the buffer tank. In large-scale solar systems, the collector array is mostly above 25m², which requires an external heat exchanger.

External heat exchangers are designed according to the following rules:

- Maximum power output: collector area in m²×600 W/m²
- Medium logarithmic temperature difference max. 5K
- Dimensioning of external heat exchanger with 100-200 mbar pressure losses to achieve a high flow rate. This is a compromise between pressure drop (pump) and deposits (fouling) on heat exchanger surface
- „Thermodynamically equal volume flow rates“ on primary and secondary side
- VSecondary = VPrimary×0.9

Internal heat exchangers (internal coil) can be designed according to the following rule of thumb: A 1m² collector

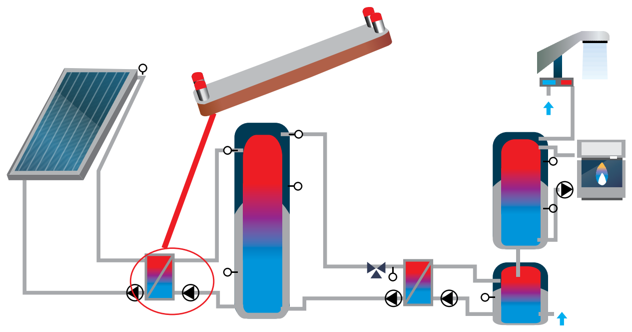


Figure 232: External heat exchanger (system 2)

field needs a 0.25m² surface.

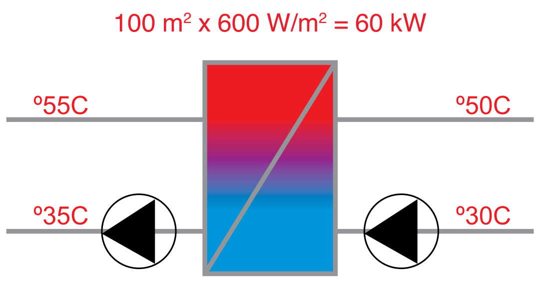
EXAMPLE 33

External heat exchanger

Assumptions:

- 100 m² collector field is installed on a hotel
- Cold water temperature at 20°C
- System type: System 2
- Minimum temperature of the buffer tank at 30°C

3. Sizing the safety components (e.g. pump, safety valve, expansion vessel)



Picture 233: Designing an external heat exchanger

- Pump

A system can reach 2000h/a or more, which requires an optimized pump design at both circuits. The recommended flow rate if the collector system is at 1m² = 18-25 litre/hour (h).

Pressure loss total □pSK within the solar circuit is defined as:

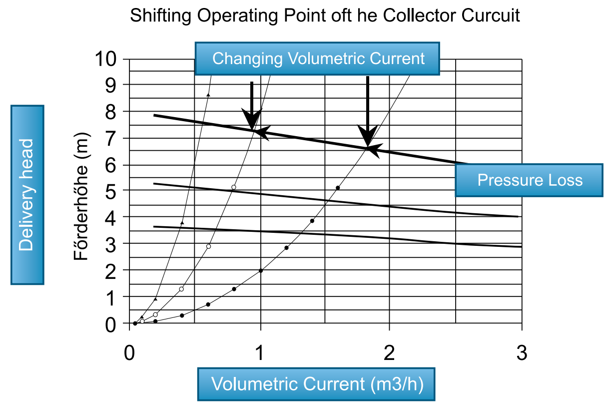


Figure 234: Diagram / characteristic curve from a standard pump.

EQUATION 10:

$$\Delta p_{SK} = \Delta p_{collector\ field} + \Delta p_{piping} + \Delta p_{heat\ exchanger} + \Delta p_{components}$$

To choose the suitable pump according to the pump curve or selection software (e.g Wilo or Grundfos), the flow rate and total pressure loss in the solar circuit needs to be known.

EXAMPLE 34

Pump selection

Assumptions:

- 100m² collector field is installed on a hotel
- Flow rate is at 100m²×18 l/m² an hour

→ = 1800 l/h = 1.8m³

- Maximum delivery height of the pump here is at 6.5m
- Total pressure loss □pSK must be lower than 6.5 m

Safety valve

The safety valve has to be dimensioned following the EN 12976 and 12977 standards (Table 18). Therefore, the safety valve must be aligned to the collectors or collector group and able to drain their maximum output:

Optical efficiency eta0×1000W/m² = 0.8×1000W/m² = 800W7m²

Only safety valves that are designed for a maximum of 6 bar and 120°C and have the code letter “S” (solar) in their component code should be used. Even the solar specific safety valves cannot be directly used at the heat exchanger on the collector side, but are mounted in flow direction in the return of the solar system after the non-return valve. It must be ensured that the temperature level does not exceed 120°C at the collector. The solar thermal equipment has high requirements regarding temperature resistance. Special valves and other components for solar thermal have temperature resistance of 120-130°C. Therefore, they can be installed on the cold side of collectors (return flow) where water flows back from the tank, whereby the secondary side can reach up to 150°C.

Table 18: Valve size dimensions according to collector area

Valve size (dimension inlet diameter)	Collector area (m²)
DN15	50
DN20	100
DN25	200
DN32	350
DN40	600

Expansion vessel

The expansion vessel fulfils 3 important functions:

1. It provides the fluid supply that is necessary to balance the volume decrease caused by very low temperatures and degassing during operation
2. It absorbs the expansion of the heat transfer medium caused by
3. rising temperatures at normal operation
4. It absorbs the volume expansion caused by steam building during stagnation phase

The expansion vessel calculation is quite time consuming and needs to involve (1) the collector field volume, (2) the total system volume, and (3) the expansion volume considering the system temperatures. The calculation of an expansion vessel can be done by using selection software, formulas or with the help of a monogram (figure 235).

4. Sizing the buffer tank or DHW tank

The buffer or DHW tanks are sized according to the heat amount that has to be stored.

In general the following formula can be applied:

Equation 11:

$Q = m \times cp \times dT$

Based on the connected collector area, there are some general rules that need to be applied for the specific solar storage capacity in litre/m² collector array:

- 50-70 liters buffer volume for m² collector array
- If necessary, up to 180 litres buffer volume for m² collector array

The tank volume may vary, depending on the load profile and peak amount of water tapped at a point of time during the day. In general, oversizing the tank has no positive effect on the system utilization level, which can be seen in figure 23.

5. Sizing the preheat tank

There is a preheat DHW tank installed in system type 2. The basic rules for dimensioning the preheat tank and heat exchanger from the buffer tank to load the preheat DHW tank are displayed in figure 239.

Relative to the total cylinder height, the two sensors should be positioned 20% away from the cylinder head and floor (figure 240).

6. Sizing the fresh water station

When sizing the DHW production as a continuous flow, the maximum occurring peak flow is relevant. In contrast, the daily hot water consumption is used when sizing the DHW production, based on the hot water tank principle. The total flow equals the sum of all individual flows together and can be determined by taking the simultaneity factor and peak flows into account (figure 241). Figure 241 can be used to determine the necessary module size.

The peak flow and size of the fresh water station in litre per minute is based on the simultaneity factor according to DIN 4708. Simultaneous means the frequency of tapping DHW at the same time in %. Other simultaneity factors, based on measurements from the technical university in Dresden, Germany, will lead to smaller fresh water stations due to a smaller simultaneous factor.

Red line translated: Simultaneity factor DIN4708

Blue line translated: Simultaneity factor according to performed measurements

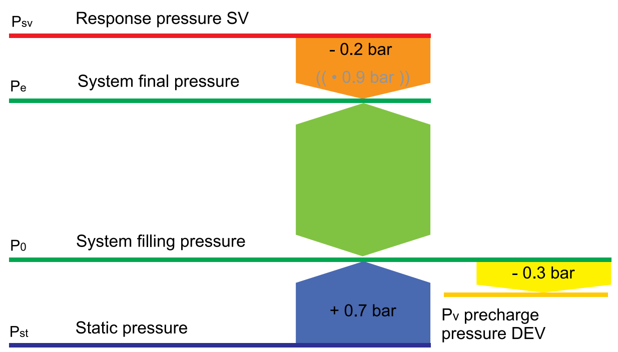


Figure 235: Typical pressure conditions of a solar thermal system

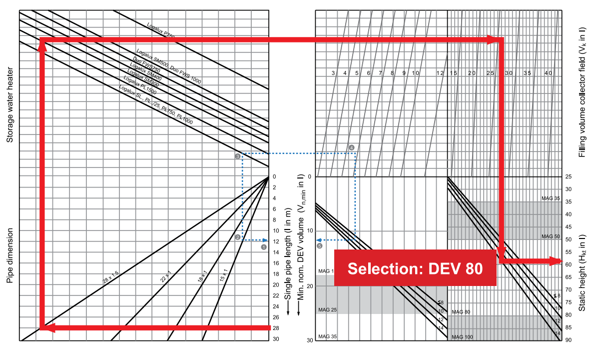


Figure 236: Dimensioning the expansion vessel with the help of a monogram

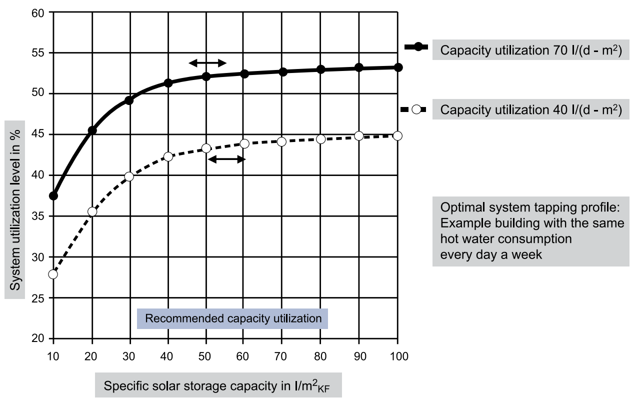


Figure 237: Specific solar storage capacity in litre/ m² collector array.

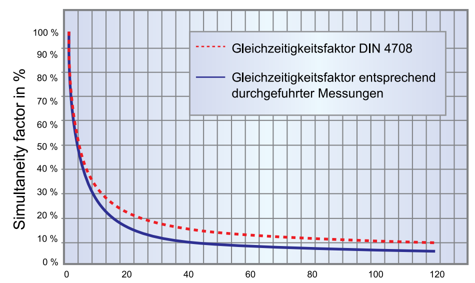


Figure 238: Specific solar storage capacity in litre/ m² collector array.

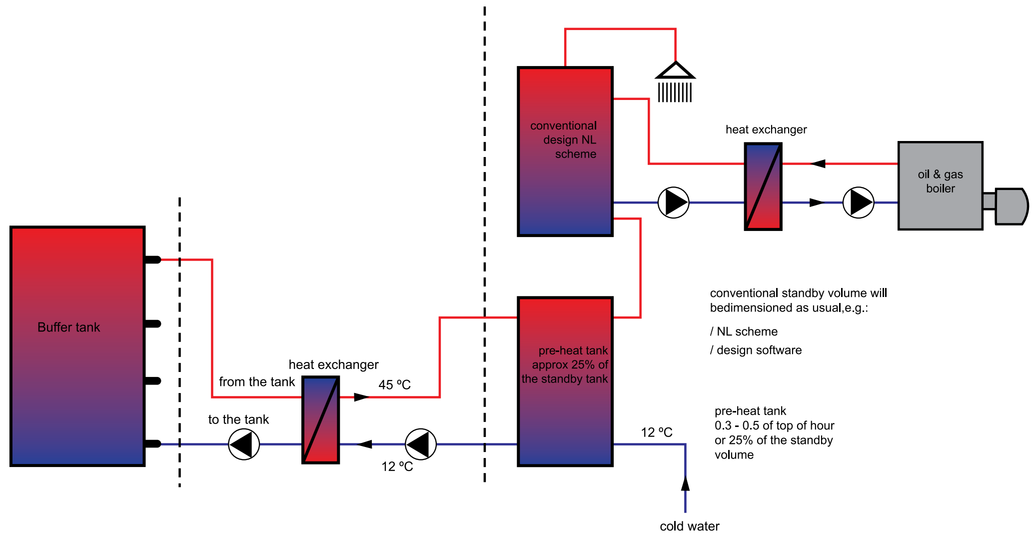


Figure 239: Basic rules for dimensioning the preheat tank and heat exchanger

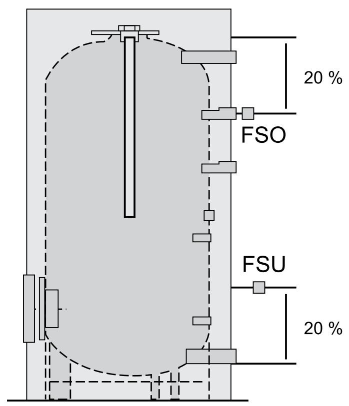
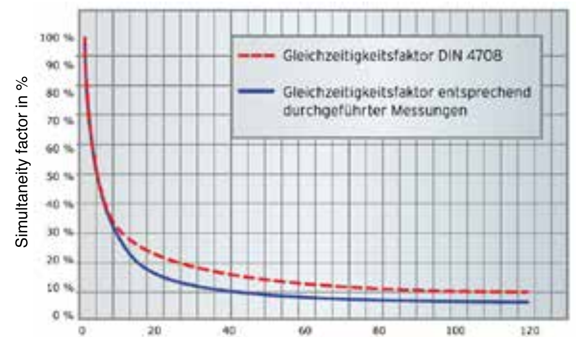


Figure 240: Sensor positions on the preheat tank



Red line translated: Simultaneity factor DIN4708
Blue line translated: Simultaneity factor according to performed measurements

Figure 242: Simultaneity factor acc. to DIN 4708 and Technical University Dresden

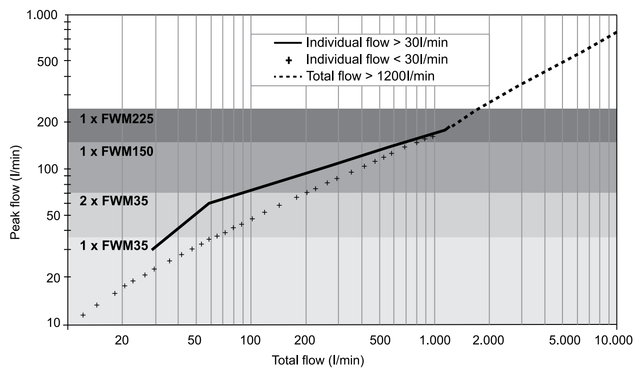


Figure 241: Peak flow with hotel systems

7. Sizing pool heating

When sizing the solar thermal heating system for the swimming pool, heat losses through evaporation and weather conditions have a significant influence on the design. Therefore, the system can only be sized using approximate figures. The system size is generally based on the surface area of the pool, however a specific water temperature over several months cannot be guaranteed. The solar yield per collector area is almost independent of the type of collector used. For many hotels, pool heating is only relevant during summer months and only low collector temperatures are required. Simulation programs, such as Logasoft GetSolar or T-SOL, are also useful design tools that take additional parameters into account, such as wind protection, pool colour, service lifetime and fresh water supply.

For existing swimming pools with reheating (indoor or outdoor), it is important that the design includes actual cooling losses. These can be calculated by switching off the pool reheating for 2 to 3 days, whilst using the pool in the meantime and measure the temperature drop of the pool water at the end of the reheating pause. Afterwards, the energy demand per day is calculated from the temperature drop and the pool content.

The collector area is designed using the typical energy yield of a solar thermal system of approx. 4kWh/m2 aperture area on a sunny summer day at southern orientation, no shading, and an average collector temperature level of 30-40°C.

Swimming pool heat losses occur due to:

1. Convection
2. Evaporation
3. Heat radiation
4. Heat conduction

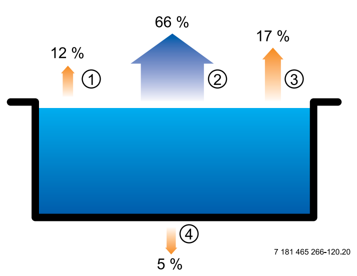


Figure 243: Swimming pool heat losses

EXAMPLE 35

Sizing swimming pool heating system

Assumptions:

- Pool surface area 32 m²
- Pool depth 1.5m
- Energy yield approx. 4kWh/m² from the collector
- Temperature drop over 2 days equal to 2 K

Required information:

- Energy demand per day
- Recommended collector aperture area

Calculation:

32 m²×1.5 m×1,163 Wh/m³K×1 K = 55.9 kWh

55.9 kWh/4 kWh/m² = 14 m²

Calculating the pipework

Pipelines and connections in the solar circuit must fulfil the following requirements:

- Enduring temperature resistance from -20°C or the lowest external temperature in winter to 180°C or the highest idle temperature in summer
- Enduring pressure resistance up to 6 bar or the maximum operational pressure of the system and large systems up to 10 bar
- Resistance against propylene glycol anti-freeze

The pressure losses result in the collecting pipelines, based on the specified flow volume. Figure 244 illustrates the pressure losses according to copper piping, 40% FS anti-freeze concentrate and a medium temperature of 40°C. The flow speed in the pipe is between 0.4 and 1m/s and the resulting pressure loss approx. at 1 to 3 mbar/m.

It is crucial to have all pipelines and armatures insulated throughout the system. The materials installed in the solar circuit must have a temperature resistant insulation up to approx. 180°C, such as Aeroflex SSH or Armaflex HT. External pipelines must also be UV- and weather-resistant, as well as waterproof and protected against damage caused by external influences through a steel shell. Further, the front- and end covers of the steel shell have to be thermally separated from the pipeline.

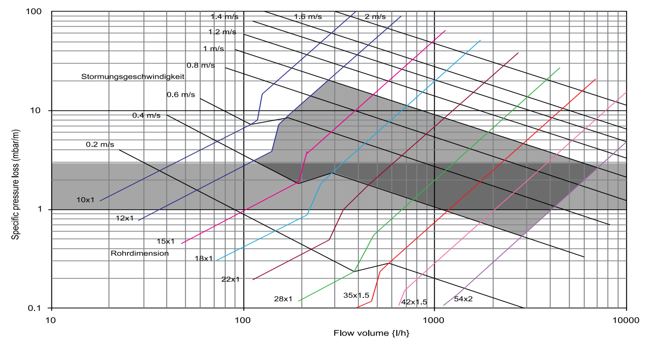


Figure 244: Pressure loss diagram for copper piping (40% FS, 40°C)

5.2 TECHNICAL SPECIFICATIONS FOR SOLAR THERMAL SYSTEMS

5.2.1 COMPONENTS

Solar thermal system

The following section describes the main parts of the solar thermal circuit. The components are often pre-assembled in standard modules.

The solar thermal system provides hot water or a hot antifreeze medium to a buffer tank through the transfer of solar irradiation into heat via a solar collector. The solar collectors can be arranged as pre-defined or pre-assembled units (i.e. power modules) with certain collector areas for each unit. The heat in the power modules is transferred to a heat exchanger at the interface module via circulation of the solar pumps in the drive module. The whole operation is controlled by a so-called solar command.

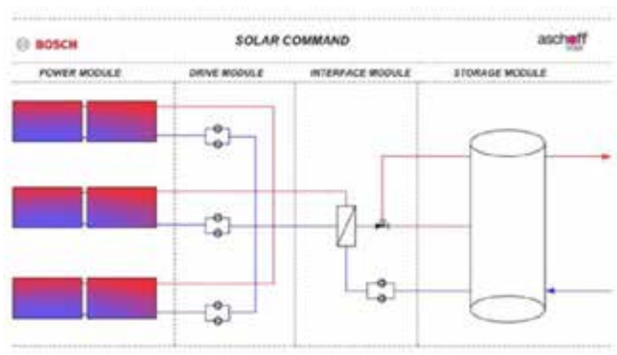


Figure 245: Diagram of a solar Thermal system

The solar thermal system includes the following components:

- Power modules
- Support structure
- Pressure control system
- Solar side piping and insulation
- Solar command system
- Secondary side piping and insulation
- Solar storage tank (i.e. storage module)

Each power module includes the following components:

- Solar collectors
- Connections between collectors
- Stop valves flow setter at each collector row
- Valves for rinsing, filling and draining
- Air bleeders and central air separators
- Piping and fittings

Figure 246: Pre-assembled complete solar thermal system with solar command (e.g. controlling module), drive module (e.g. pump module) and interface module (e.g. transfer unit)

Solar command system

The solar command system is a pump and control unit that is used to move water in the closed solar circuit, in order to exchange thermal energy via heat exchangers to the customers coupled to the hot water system. Its external connected sensors include all necessary electronic and hydraulic elements to operate and control a solar thermal system according to the system design.

The solar command controls the complete solar system. It manages the transfer of heat to the storage tank and offers the possibility to monitor and set the system either on-site or remotely via a touch screen online interface. The solar command includes all needed components of wiring, electronics, and sensors, which are necessary to operate the solar system.

Figure 247: Control unit of a solar thermal system – pre-assembled in a control box

The solar command includes the following components:

- PLC with control software integrated in an industrial cabinet
- Meters and sensors
- Power electronics
- Touch screen

The drive module includes the solar pump(s) and necessary sensor elements to run and control the solar circuit. Each power module can be connected to a separated pump group. Depending on the system size, the drive module is combined to the interface module for smaller systems in pre-assembled standard units (e.g. solar stations), or installed in separated frames in the storage module or stand-alone cabinets.

The drive module includes the following components:

- Solar pumps
- Connection to pressure control system and safety devices
- Filling and rinsing devices

Interface module

The interface module is a pre-assembled unit, which includes the heat exchanger to transfer the energy to the secondary side, consumer or storage tank. The pumps and heat metering for the solar and secondary circuit are integrated at the secondary side. Depending on the system size, the interface module can be combined with the drive module for smaller systems in pre-assembled standard units (i.e. solar stations) or installed in separated frames in the storage modules or stand-alone cabinets.

The interface module includes the following components:

- Secondary Pumps
- Heat Exchangers
- Flow Meters and Heat Meters
- Switching valves if required

Figure 248: Pre-assembled pump group to run the solar circuit

Figure 249: Pre-assembled module to transfer the heat to the storage

Support structure

The support structure of a solar thermal system is usually made out of aluminium or galvanized steel and mounted to the existing ground or roof. Depending on the location and system design, the power modules can be installed either parallel to the roof, on industrial pitch roofs or on flat roofs/grounds with the help of support angles to give the correct inclination for the optimal performance (picture 249).

The support structure includes the following components:

- Horizontal collector support profiles
- Roof fasteners in case of roof parallel installation
- Collector clamps to fix collectors on the support structure
- Profile angles in case of flat roof or ground installation
- Concrete foundations or ballasting (if required)
- Rubber mats under the structure (if required)

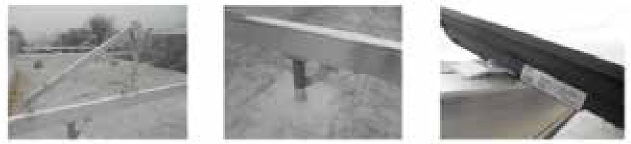


Figure 250: Support structure for a flat roof

Figure 251: Pressure and safety components

Figure 252: Standard sea-freight container as low-pressure buffer tank

Pressure control system

The pressure control system ensures that the water volume in the power modules and solar piping can expand without damaging the system in the closed circle. It is an essential safety device, which releases liquid from the solar circuit, in case the system pressure exceeds the relief pressure of the included safety valve.

The pressure control system includes the following components:

- Expansion tank
- Pre-expansion tank (if required)
- Safety valve

Storage module

The storage module is the solar storage in the solar system to store the generated energy at daytime to provide it during night time. The storage tank can either be a pressurized steel tank or a sea-freight container, which is made out of anti-corrosive and long lasting PP-plates and insulated against heat losses through hard foam insulation. Hydraulic components, such as the complete or partial solar command system can be integrated in the remaining space of the container to allow plug and play on-site. Therefore, all parts can be assembled and tested before the installation.

The storage module includes the following components:

- Sea-freight container
- Integrated hot water storage tank
- Thermal insulation of storage tank
- Overflow connection
- Integrated solar command system

Piping and insulation

The piping connects the power modules with the drive and interface module on the solar side, whereby the storage module with the process is assembled at the secondary side. The piping material and connection technology is installed with either thread connections or each piping part is simply pressed into one another. Thermal insulation reduces heat losses and the insulation cover protects from environmental influence and animal picking.

Figure 253: Perfect copper pipework with insulation in aluminium casing

The piping and insulation includes the following components:

- Piping in copper, steel or stainless steel
- Piping support and connections
- Thermal insulation
- Insulation cover

Sensors

Flow sensors are used to check the flow rates in the solar and secondary (tank/consumer) circuit of the solar thermal system. The flow sensors deliver the flow rates for the calculation of heat and energy, provided by the system. All flow sensors can be pre-installed in the module. The pressure sensors in the solar circuit are inspecting the pressure in the solar system as part of the preventive maintenance concept. Pressure drops as a result of leakages, but assist in identifying smooth changes. Temperature sensors are used to check all relevant temperatures in the system for control functions or preventive maintenance. An irradiation sensor is used for performance control of the system.

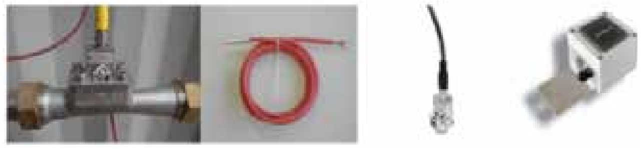


Figure 254: Flow-sensor, temperature sensor, pressure sensor an irradiation sensor (from left to right)

Heat meters

Heat meters are used for energy metering at the outlet of the solar system to give performance control and transparency of the hot water supply. The metering is connected to the pre-mounted module, where the system performance can be checked on an hourly or daily basis.

Figure 255: Different kinds of heat meter

Dirt traps

Dirt traps protect the important components of the solar thermal system from sediments in the water. The included filter must be cleaned according to the maintenance schedule and at significant changes of flow rates in the system. Dirt traps are installed in the solar circuit module. It is recommended to install additional dirt traps in the piping, which run along the solar storage tanks and the cold water supply. In case of bad water quality, it is strongly recommended to use reverse flushable filters in the tank piping and the cold water supply of the system.

Picture 222: Dirt trap

Figure 256: Balancing valve to have the same flow rate in each collector line and as the same temperature outlet of the collector field

Flow setters

Flow setters can be used in each collector line of the power modules to adjust the exact designed flow rate, which is necessary to ensure the required temperature and smooth operation of all power modules.

Air bleeders and air separators

Air bleeders are installed to ensure stable and safe operation of the system at each collector line of the power modules. The air bleeder releases air in case of filling and operation of the system. Central air separators are necessary in each power module circle to increase operational safety by releasing air, which is not released by the single air bleeders.

Figure 257: Air bleeder

Fresh water storage tanks

Pressurized hot water storage tanks are used on the consumer side of the system as pre-heating or stand-by tanks, which are directly heated by the existing back-up heating system.

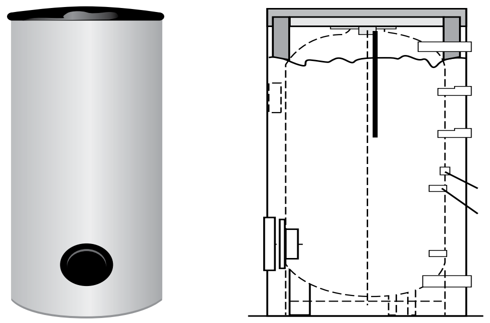


Figure 258: Standard buffer tank

Picture 226: Three-way valve for buffer tank load in different temperature levels

Three-way switching valves

Switching valves allow charging the storage modules (i.e. buffer tank) on different levels, depending on the achievable temperature in the solar system to optimize the solar performance.

5.2.2 STANDARDS

The following chapter gives an overview of regulations and guidelines for designing a solar thermal system.

IMPORTANT: The regulations listed here only represent a selection and is not an exhaustive list on standards of solar thermal systems.

Installations and commissioning have to be carried out by professional heating contractors. Also, accident prevention according to local regulations has to be taken during the entire installation. The practical implementation is subject to current technical rules and safety equipment should be installed in accordance with local regulations. Furthermore, when installing and operating a solar collector system, it is recommended to observe the requirements of the relevant national building regulations, the stipulations for listed buildings and any local building regulations.

Table 19: Important standards, regulations and EC Directives for the installation of solar collector systems

Regulation	Designation
	Installation on roofs
DIN 18338	VOB1); roofing and roof sealing work
DIN 18339	VOB1); plumbing work
DIN 18451	VOB1); scaffolding work
DIN 1055	Design loads for buildings
	Connection of solar thermal systems
DIN-EN 12975-1	Solar thermal systems and their components - collectors – Part 1: General requirements; German version
DIN-EN 12976-1	Solar thermal systems and their components - prefabricated systems – Part 1: General requirements; German version
DIN V ENV 12977-1	Solar thermal systems and their components - customer-specific systems – Part 1: General requirements; German version
VDI 6002	Solar DHW heating
	Installation and equipment of DHW cylinders
DIN 1988	Technical Regulations for Drinking Water Installations (TRWI)
DIN 4753-1	DHW cylinders and DHW heating systems for drinking and process water; requirements, identification, equipment and testing
DIN 18380	VOB1); heating systems and central DHW systems
DIN 18381	VOB1); gas, water and drainage installation work within buildings
DIN 18421	VOB1); insulation work on technical installations
AVB 2)	Water
DVGW W 551	DHW heating and pipework systems; technical measures for reducing the growth of legionella
	Power supply
DIN VDE 0100 I	Installation of HV systems with rated voltages up to 1000V
DIN VDE 0185	Lightning protection system
VDE 0190	Main earth bonding of electrical systems
DIN VDE 0855	Aerial systems - to be applied as appropriate
DIN 18382	VOB1); electrical cable systems in buildings

Technical regulations for the installation of a thermal solar heating system:

1) VOB Contract procedures for building works – Part C: General technical specifications for building works (ATV)
2) Invitation to tender templates for building work in over ground work, particularly with regard to residential buildings

5.3 INSTALLATION OF SOLAR THERMAL SYSTEMS

5.3.1 INSTALLATION

THE SOLAR CIRCUIT

There are two possibilities of operating the solar circuit:

1. Water as heat transfer medium
2. Water-glycol heat transfer medium

1. WATER AS HEAT TRANSFER MEDIUM

The water in the solar circuit has to fulfil special conditions that are given by the supplier of the collector, heat exchanger and pipes. The water conditions have to be tested on their sulphate and chloride content.

2. WATER-GLYCOL HEAT TRANSFER MEDIUM

To protect the solar system against corrosion, it is recommended to run the system with antifreeze of at least 25% of the system volume, depending on the product used. When antifreeze is used, all components in the solar thermal system, including flexible seals in the valve seats and diaphragms in the expansion vessels must consist of glycol-resistant material and carefully sealed, as water/glycol mixtures flow quicker than water. Regarding the sealing material, aramid fibre has proven useful, whereby graphite strings are suitable for packing of gland end seals. However, hemp-packing seals have to be coated with temperature and glycol-resistant thread sealant paste, such as ‘Neo Fermit universal’ or ‘Fermitol’ from Nissen. For systems with high efficient flat collectors, the antifreeze medium must offer safe operations at temperature levels ranging from -30°C to +170°C. Its is therefore important that the vacuum tubes run on a high temperature resistant solar fluid, such as Solarfluid LS from Tyforop.

ROUTING THE PIPEWORK

In the collector circuit, copper, steel, stainless steel as well as corrugated stainless steel pipes can be used. Plastic pipes are not suitable because of their lack of temperature resistance. Steel pipes are installed with larger solar power systems starting from size DN 35. Copper pipes can be connected with hard solder or press fittings with the approval from the manufacturer. All joints in the solar circuit must be hard soldered. Alternatively, press fittings can be used if they are suitable for glycol/water mixtures and the correspondingly high temperatures of 200°C. All pipework has to be routed with a rise toward the collector array or the air vent valve, in case one is installed. When routing the pipework, take the thermal expansion into consideration. The pipes, including the bends, sliding clamps and compensators, must allow room for expansion to prevent damage and leaks. Plastic pipes and zinc-plated components are not suitable for solar thermal systems.

Pipelines and connections in the solar circuit must fulfil the following requirements:

- Withstanding temperature resistance from 0-180°C
- Withstanding pressure resistance up to 6 bar or the maximum operational pressure of the system; with large systems up to 10 bar
- Resistance against propylene glycol anti-freeze

THERMAL INSULATION

In new buildings, it is possible to route connection lines in unused chimneys, airshafts or wall slots. It is recommended to seal open shafts with suitable materials to prevent increased heat loss through convection. The thermal insulation of the connection lines must be designed according to the operating temperature of the solar thermal system. Therefore, only insulation materials with correspondingly high temperature resistance, such as EPDM rubber, must be used. The thermal insulation for outdoor installations has to be UV and weather-resistant.

Mineral wool is only suitable for outdoor installations, in case a metal sheet casing exists. Otherwise the material absorbs water and then loses its thermal insulation properties. The connection sets for the solar collectors also have to have UV and high temperature-resistant thermal insulation made out of e.g. EPDM rubber.

Table 20: Thickness of the thermal insulation for a selection of products for solar thermal systems

External pipe Diameter (mm)	Mineral wool insulation thickness (relative to α = 0.035W/m · K) (mm)
15	20
18	20
20	20
22	20
25	30
28	30
32	30
35	30
42	40

EXTENSION LEADS FOR COLLECTOR TEMPERATURE SENSORS

When routing the pipework, a 2-core lead of up to 50mlead length 2 × 0.75 mm^2, should be laid alongside for the collector temperature sensor. Such leads are often included in the insulation of the special twin-tubes. If the extension lead for the collector temperature sensor is routed together with a 230-V cable, the cable must be screened. The collector temperature sensor should be fitted in the sensor lead pipe of the collectors, close to the flow manifold.

Figure 260: Mineral wool with a metal sheet casing

Air vent valve

In case no filling stations or air separators are used, solar thermal systems with flat-plate collectors are ventilated via a quick-action air vent valve at the highest point of the system. After the filling process, it is very important to close this valve so that no vaporous solar fluid can escape from the system, if stagnation occurs. It is necessary to provide an air vent valve with dormers at the highest point in the system and at every downward direction change.

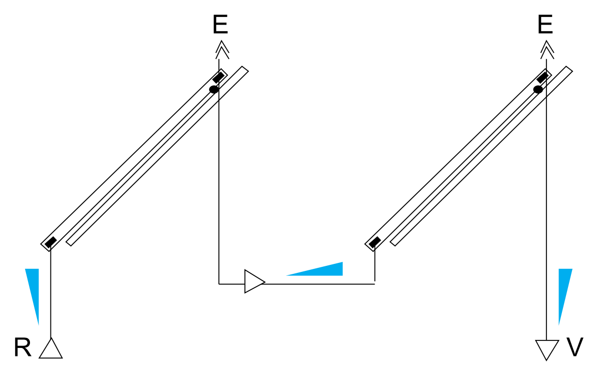
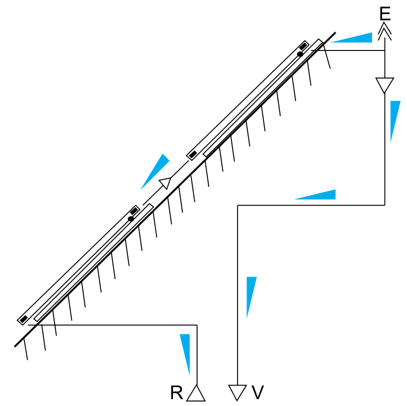


Figure 261: Hydraulic scheme with an air vent valve for each collector row, using flat roof installation as an example (series connection)

If there are several collector rows, provide an air vent valve for every row if the system cannot be ventilated via the top row. The air vent should be assembled via a metal, fully automatic air vent valve. Air vent valves with plastic floats cannot be used in solar thermal systems, due to their temperature limitations. If there is insufficient space for a metal and fully automatic air vent valve with an upstream ball valve, it is best to install a manual air vent valve with a drip pan.



E= Air vent valve
R= Return
V= Flow
E= Air vent valve
R= Return
V= Flow

Figure 262: Hydraulic scheme with air vent valve above the top row, using rooftop installation as an example (series connection)

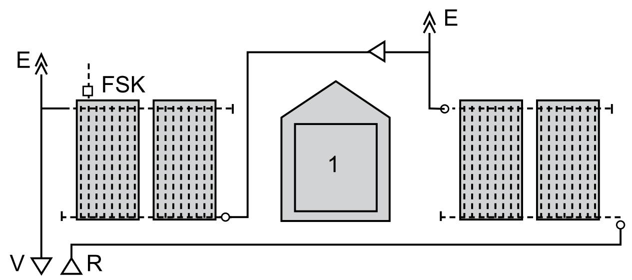


Figure 263: Hydraulic connection of collector arrays that are split by a roof dormer

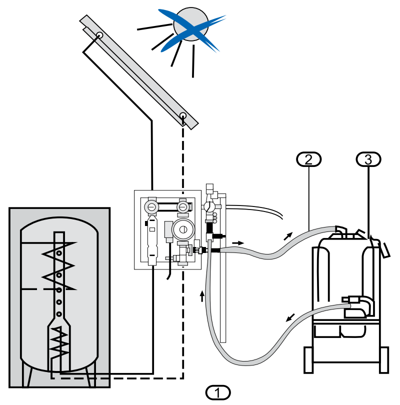
FILLING STATION AND AIR SEPARATOR

A solar thermal system can also be filled using a filling station, which has the advantage of releasing a large proportion of the air in the system during the filling process. For smaller system up to 30m², an air vent valve on the roof is unnecessary, as during operation the residual micro bubbles left in the medium are discharged.

The benefits of the system are:

- Reduced installation effort because no air vent valves are required on the roof for smaller systems up to 30m²
- Simple and quick commissioning, i.e. filling and ventilation in one step
- Optimally vented system
- Low maintenance operation

If the collector array consists of several rows connected in parallel, it is necessary to install a shut-off valve in the flow of each individual row. During the filling process, each row is filled and ventilated individually.



1= Pressure hose
2= Return hose
3= Filling station

Figure 264: Flushing a standard system

SENSOR POSITIONING

All sensor positions have to be checked carefully, whether they have been fixed accurately Especially the collector sensor must be controlled, as loosely attached collector sensors can be displayed by external influence such as bird picking.

CONTROLLER

Before commissioning the solar thermal system, all pumps and valves should be switched on manually in the controller to ensure all valves have the right position and all pumps are connected correctly.

The controlling parameters are adjusted to the current system hydraulics, in coordination with conventional reheating system and adjusted to a central building control system if present.

The main parameters that have to be adjusted in the controller are:

- Limitations of maximum temperatures in the storages
- On/off hysteresis of the pumps and valves
- Activation of some special function

→ At least the controller must be switched into auto-modus.

5.3.2 GENERAL GUIDANCE ON INSTALLATION TIMEFRAMES

Throughout the installation, allow for at least two installers to assemble the solar collectors. Every installation on a pitched roof requires modifications to the roof. These modifications have to be done by specialists, such as roofers and plumbers that are consulted prior to the installation.

Many manufactures offer training courses on installing solar thermal systems, however the supervision of a specialist is necessary. In general, the required installation sets include all necessary accessories with the associated installation instructions for any thermal installation type. It is advised to read the instructions for the selected thermal type carefully before the installation.

Times for collector installation

The times in the table below only apply to the collector installation with mounting structures and connections to a collector row. Times for safety precautions, for moving the collectors and installation systems onto the roof, or for roof modifications (e.g. adapting and cutting the roof tiles) are not taken into consideration. A roofer should estimate these efforts and their required time. The time calculation for planning a solar collector system is based on experience and depends on local conditions. Therefore, the actual installation times at the site might differ depending on the country's infrastructure, technical know-how, etc.

Table 19: Installation with two installers for collectors in a small system of up to 20 collectors on roofs with an inclination ≤ 45°, not including handling time, time for safety precautions or making a substructure on site

Installation version and scope	Guidance on installation times	
	For 2 collectors	For each additional collector
Rooftop installation	1.0 h per installer	0.2 h per installer
Roof integration	2.5 h per installer	1.0 h per installer
Flat roof installation with ballast troughs	1.5 h per installer	0.3 h per installer
Wall installation at 45°C	2.5 h per installer	1.5 h per installer

5.3.3 OPERATION & MAINTENANCE

Like every technical application, also a solar thermal system must undergo routine maintenance to sustain trouble-free functionality, the highest possible solar output and a long lifetime. It is recommended to have regular check-ups of the system at least every 3 years.

A standard maintenance includes the following services:

- Visual checking of the main components, like collector, storage and valves
- Checking system data, like system pressure
- Optimising set values in the controller or logging data
- Checking the heat transfer medium (e.g. anti-freeze, pH values)
- Checking general system check points
- Checking solar yield

Especially the control of the yearly collector yield is very important and should be measured, as it varies depending on several factors:

- Location and global radiation
- Kind of collector type
- Heat consumption
- Load profile of the heat consumption
- System design of the solar thermal system

A detailed dynamic simulation of the solar thermal system at the planning phase via standard simulation software, such as TSOL, Getsolar or Polysun, is the best way to compare the real collector yield with the expected one. The existing data might differ up to 25% to the simulated data, due to possible lower consumption as expected or differing climate. In general the daily collector yield on a sunny day, cold storages and normal expected heat consumption should be around 3-4kWh per m² collector on the roof.

In practical terms, with an annual solar irradiation between 1650 kWh/m² and 2700 kWh/m², solar energy can be used effectively in every country of the MENA-region. On average, the efficiency of a solar thermal system in the MENA-region is around 40-55%.

Formula for the yearly yield:

Global radiation × system efficiency

= min. 1650 kWh/m²a × 0.4 = 660 kWh/m² a

= max. 2700 kWh/m²a × 0.55 = 1485 kWh/m² a

5.3.4 CHECKLISTS

Each installer has his own checklist for commissioning a solar thermal system (figire 265).

The most important points that have to be checked are:

- Collector sensors must fit inside solar panel
- No valves should be installed onto solar panels which can destroy the collector
- 2 core sensor cable to be wired from collector sensor to the control panel in plant room
- Pipework pressure tested at 6 bar
- Pipework and connections suitable for solar temperatures of up to 130°C
- Expansion vessel piped to solar pump station with isolating and drain valves fitted
- 230v 1phase supply to control panel
- Solar fluid left in plant room

Plant room requirements:

- 230v/110v 1phase electrical supply
- Cold feed tap available in plant room
- LAN or WLAN connection for data monitoring


SOLAR THERMAL COMMISSIONING CHECKLIST

Figure 265: Checklist for commissioning a solar thermal system

5.3.6 DO´S AND DON´TS

The main mistakes that have to be avoided when installing and using solar thermal systems are described in the following often occurring system faults:

1. INSTALLATION

Do not install the solar system during full sun radiation on the collector field.

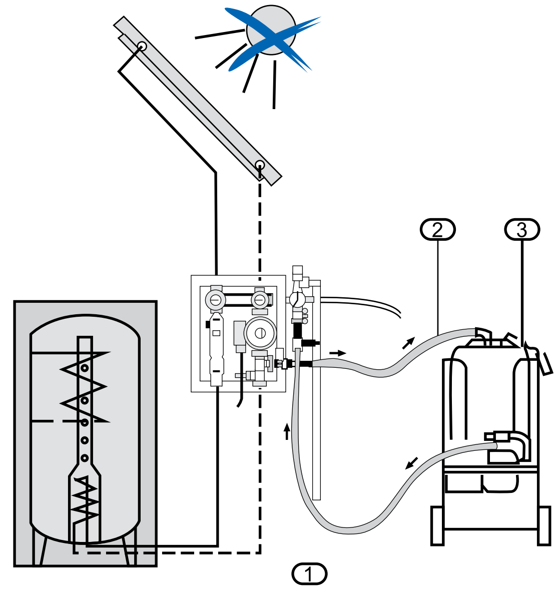


Figure 266: Wrong commissioning during a sunny day. Attention: Risk of scalding!

2. HEAT TRANSFER MEDIUM

Using a wrong or not permitted heat transfer fluid.

- Use only permitted fluids
- Follow installation instructions

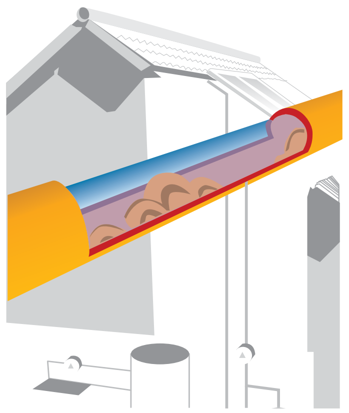


Figure 267: Wrong heat transfer medium will damage the system

3. DRINKING WATER MIXER

In most cases there are no drinking water mixers installed. If the hot water temperature in the DHW storage tank is not limited to a maximum of 60°C by solar controller, there is the danger of extremely high temperatures at the taps, which can burn the consumer/hotel guest. For end-user protection, a thermostatic mixer should be installed in the outlet of solar system, to continuously adjust the hot water temperature between +30°C and +65°C.

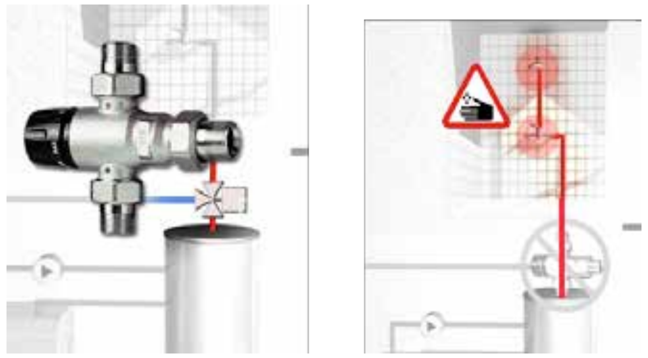


Figure 268: Thermostatic mixer should be installed in the outlet of solar system for end-user protection.

4. THERMAL INSULATION IN THE INSTALLATION

The whole piping system has to be well insulated. In case the water pipes are exposed, they have to be protected against aggressions (i.e. mechanical protection), in order to avoid pipes bursting. A proper thermal insulation has 3 main benefits: (1) minimizes thermal losses at hot water pipe, (2) protects against possible frost damages at cold water pipes, and (3) increases the system's efficiency.

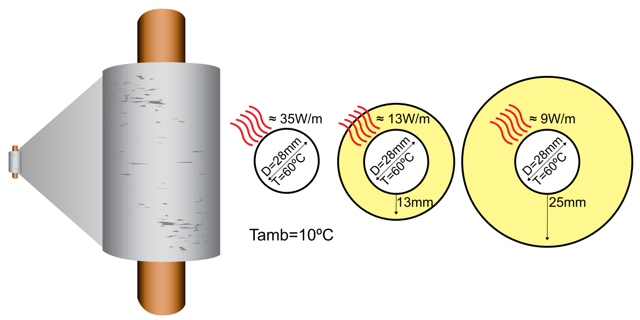


Figure 269: Well-insulated pipes will get a high efficiency system

5. MEMBRANE EXPANSION VESSEL IN THE INLET COLD WATER CIRCUIT

Expansion vessels have to be installed at the cold-water circuit, even in fresh water systems, whilst considering the total volume in the hot water and circulation circuit. It is recommended to pay attention to the coefficient of expansion of the water itself, in order to calculate regarding water pressure, water volume and pressure relief activation values of the security valve. Also, do not install interception valves between the tank and the vessel.

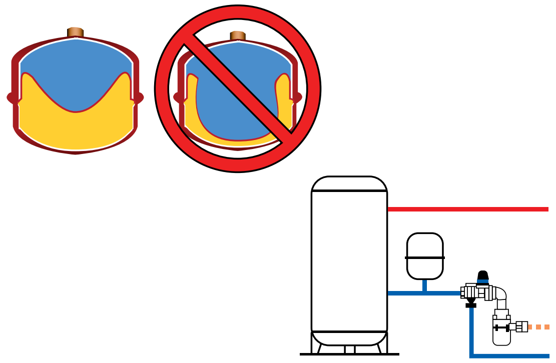


Figure 270: Expansion vessels are often too small. Interception valves between tank and vessel are not allowed

6. HOT WATER USE RECOMMENDATION

It's strongly recommended to use flow limiter to prevent excessive water consumption during tapping operation. The use of flow limiter, e.g. from Caleffi, assists tank stratification and hot water conservation during excessive water tapping.

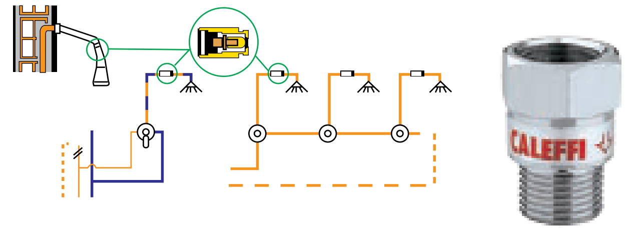


Figure 271: Flow limiter

7. SAFETY FIRST

Especially during the installation on the roof, follow safety guidelines. It is mandatory to wear safety belts.

Figure 272: Follow the guidelines for safe installation of solar systems on roofs

06

A STUDY ON SOLAR SYSTEMS FOR HOTELS IN THE MENA REGION

Chapter Six

The following case studies are a representation of solar systems in Egypt that are demonstrating necessary quality standards for the installation and materials used.

CASE STUDY: HOTEL IN EL GOUNA, EGYPT

Hotel information:

- 2 Buildings with 79 and 155 rooms
- Spa facilities
- Outdoor pool
- Standard facilities, kitchen, laundry

Demand Information:

Electricity demand:	47kWh per room/day
Required peak power: approx.	600kW (daily profile not available)
Water demand:	791 litre/room/day
Fuel demand:	2.3 litre fuel/room/day
Yearly occupancy:	74%

Hotel demand profiles:

→ Total yearly power demand: 2,700,000kWh
→ Total yearly water demand: 44,930m3
→ Total yearly fuel demand (Diesel): 107,500 litres

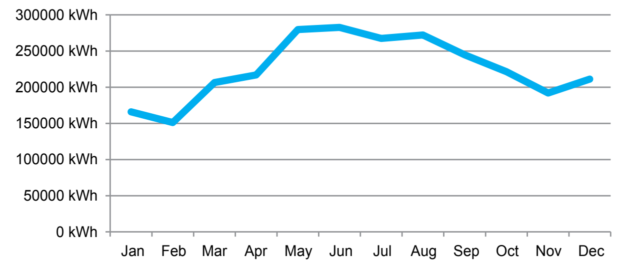


Figure 273: Yearly demand profile - Power

EXISTING HOT WATER SYSTEM

The hotel's hot water system is a diesel boiler with a hot water storage tank for the155 rooms and pool heating. Their existing solar thermal application has a back-up heating system via electric heaters for the 79-room building. The thermal application is out of operation, as design, choice of materials and installation were below needed quality standards. The system has several defects, which demonstrate the importance of paying attention to basic quality standards, according to the conditions of the project's site, especially when installing in coastal areas.

The hotel's solar thermal system's defects are:

1. Corrosion due to salt and chlorides in air and water

The consequences of high levels of salt and chlorides in air and water alongside an inappropriate solar system design are strong corrosion on the collectors and support structure (figure 276). Careful choice of suitable materials is a must for any technical installation in coastal areas. Only suitable components and materials have to be used.

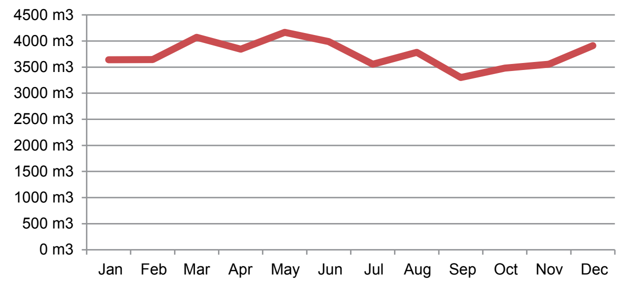


Figure 274: Yearly demand profile - Water

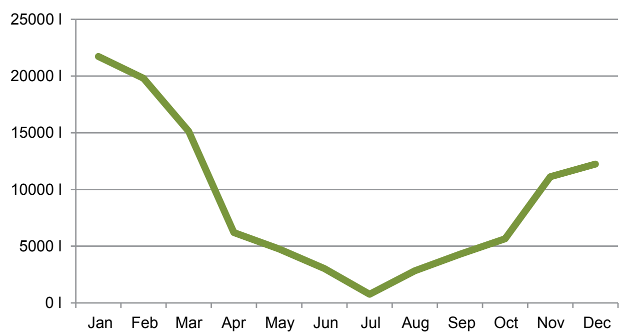


Figure 275: Yearly demand profile - Diesel

Figure 276: Corrosive collectors and support structure

2. Wrong installation materials

The materials used for installing a solar system, regardless of the type of technology – PV or thermal – only suitable and qualified components have to be used, according to the project's location. Solar piping has to withstand high temperatures, but also environmental conditions, such as UV-radiation and saline air. Pipes must be protected with suitable covers and thermal insulation is a must, to reduce losses in operation and keeping a high efficiency of the system. Plastic tubes are not suitable, as they do not withstand temperatures of above 90°C and lose their malleability due to sun exposure. Therefore plastic components are not acceptable for any type of solar systems, especially for outdoor installations. Figure 277 shows inappropriate piping, whereas figure 279 & 280 demonstrate suitable piping material. Appropriate piping material for solar systems are either materials used in boatbuilding, aluminium or anticorrosive painted piping, that are durable against salinity and sun exposure.

Figure 277: Wrong piping material for hot water or solar installation

Figure 278: Evacuated tube collectors or hermetic sealed flat plate collectors to prevent from

Figure 279: Correct Piping material for hot water or solar installations

3. Open systems at locations with bad water quality

Fresh water contains many elements that can quickly destroy a hot water system and reduce its performance, regardless whether the hot water is used in a solar application or a conventional system. These elements can include lime, chlorides, salt or iron. For this hotel in particular, the electric heaters had been destroyed within 6 months, due to high salinity and chloride content in the water. Separated circles can help to limit the damage, as instead of fresh water, special liquids with corrosion protection are used in the storage tanks and collector circles.

Figure 280: Defect storage tanks and electric heaters.

Figure 282: Qualified storage tanks with multi layer coating or anti corrosive materials and separated circles can protect from internal destruction

SUGGESTED SOLAR ENERGY SOLUTIONS:

A) Solar power

Two scenarios are presented:

1) A 50kWp solar power system on a carport

The first scenario is an installation of a 50kWp solar power system on a carport as an aesthetic element in front of the hotel. As the daily demand profile for power was not available, the system solution to install a 50kWp system first included suitable metering to record accurate data on the demand profile, as a basis for further solar extensions to increase energy savings.

2) A 250kWp solar power system on hotel building

The second scenario is to install a 250kWp solar power system on the larger 155-room hotel building. An installation of a 250kWp is still far below the peak demand and leaves a safety gap to avoid solar excess, which could not be stored or fed into the grid, as this system design assumes no feed-in tariff agreemens nor storage possibilities.

aschoff solar

Project Amortization for Solar Power System

Project:	**Hotel El Gouna**	**Location:** El Gouna, Egypt			
System type:	Self-Consumption	**degradation**	0,80 % p.a.		
System Power	50 kW	**specific solar yield:**	1750 kWh/kWp p.a.	**operational costs:**	0,2 % of invest
Energy Price (Tarif Mix):	0,11 EUR/kWh	**energy price increase:**	15% p.a.	**investment:**	76.000,00 €

year of operation	1	2	3	4	5	6	7	8	9	10
solar yield kWh/a	87.500	86.800	86.106	85.417	84.733	84.056	83.383	82.716	82.054	81.398
accumulated solar energy kWh	87.500	174.300	260.406	345.822	430.556	514.611	597.994	680.710	762.765	844.163
energy price in EUR/kWh	0,11	0,13	0,15	0,17	0,19	0,22	0,25	0,29	0,34	0,39
savings in EUR	9.625	10.980	12.526	14.290	16.302	18.597	21.216	24.203	27.611	31.498
operational costs in EUR	152	152	152	152	152	152	152	152	152	152
accumulated savings in EUR	9.473	20.301	32.675	46.813	62.963	81.408	102.472	126.523	153.982	185.328
account balance in EUR	-66.527	-55.699	-43.325	-29.187	-13.037	5.408	26.472	50.523	77.982	109.328

year of operation	11	12	13	14	15	16	17	18	19	20
solar yield kWh/a	80.747	80.101	79.460	78.824	78.194	77.568	76.948	76.332	75.721	75.116
accumulated solar energy kWh	924.909	1.005.010	1.084.470	1.163.294	1.241.488	1.319.056	1.396.004	1.472.336	1.548.057	1.623.172
energy price in EUR/kWh	0,45	0,51	0,59	0,68	0,78	0,90	1,03	1,18	1,36	1,57
savings in EUR	35.933	40.993	46.764	53.349	60.860	69.429	79.205	90.357	103.079	117.593
operational costs in EUR	152	152	152	152	152	152	152	152	152	152
accumulated savings in EUR	221.109	261.950	308.562	361.759	422.467	491.897	571.102	661.459	764.538	882.131
account balance in EUR	145.109	185.950	232.562	285.759	346.467	415.897	495.102	585.459	688.538	806.131

Investment: 76,000 EUR
Payback period: < 6 years

Figure 283: Amortization plan for a small 50kWp solar power system

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Project Amortization for Solar Power System

Project:	**Hotel El Gouna**	**Location:** El Gouna, Egypt			
System type:	Self-Consumption	**degradation**	0,80 % p.a.		
System Power	250 kW	**specific solar yield:**	1750 kWh/kWp p.a.	**operational costs:**	0,2 % of invest
Energy Price (Tarif Mix):	0,11 EUR/kWh	**energy price increase:**	15% p.a.	**investment:**	355.000,00 €

year of operation	1	2	3	4	5	6	7	8	9	10
solar yield kWh/a	437.500	434.000	430.528	427.084	423.667	420.278	416.916	413.580	410.272	406.989
accumulated solar energy kWh	437.500	871.500	1.302.028	1.729.112	2.152.779	2.573.057	2.989.972	3.403.552	3.813.824	4.220.813
energy price in EUR/kWh	0,11	0,13	0,15	0,17	0,19	0,22	0,25	0,29	0,34	0,39
savings in EUR	48.125	54.901	62.631	71.450	81.510	92.986	106.079	121.014	138.053	157.491
operational costs in EUR	710	710	710	710	710	710	710	710	710	710
accumulated savings in EUR	47.415	101.606	163.527	234.267	315.066	407.342	512.711	633.015	770.359	927.140
account balance in EUR	-307.585	-253.394	-191.473	-120.733	-39.934	52.342	157.711	278.015	415.359	572.140

year of operation	11	12	13	14	15	16	17	18	19	20
solar yield kWh/a	403.733	400.504	397.300	394.121	390.968	387.840	384.738	381.660	378.607	375.578
accumulated solar energy kWh	4.624.547	5.025.051	5.422.350	5.816.471	6.207.440	6.595.280	6.980.018	7.361.678	7.740.284	8.115.862
energy price in EUR/kWh	0,45	0,51	0,59	0,68	0,78	0,90	1,03	1,18	1,36	1,57
savings in EUR	179.666	204.963	233.822	266.744	304.301	347.147	396.025	451.786	515.397	587.965
operational costs in EUR	710	710	710	710	710	710	710	710	710	710
accumulated savings in EUR	1.106.096	1.310.349	1.543.461	1.809.494	2.113.086	2.460.233	2.856.258	3.308.044	3.823.441	4.411.406
account balance in EUR	751.096	955.349	1.188.461	1.454.494	1.758.086	2.105.233	2.501.258	2.953.044	3.468.441	4.056.406

Investment: 355,000 EUR
Payback period: < 5.5 years

Figure 284: Amortization plan for a 250kWp solar power system

B) Solar thermal:

When planning a solar thermal system, information on the demand profile of the hotel is one of the key factors of a well-functioning system. One way to collect all necessary information is to fill out a planning datasheet offered by the system provider. The better the quality of the data, the more accurate the thermal system. In some cases, a brief confidentiality agreement can help to disclose detailed information on the demand profiles of the hotel.

According to the hotel information in El Gouna, Egypt, two different solar thermal systems are proposed:

1. Replace existing solar thermal system with back-up heating via electric heaters on the 79-room building.
2. Install a new solar thermal application for the diesel boiler system with hot water storage tank for the 155-room building and pool heating.

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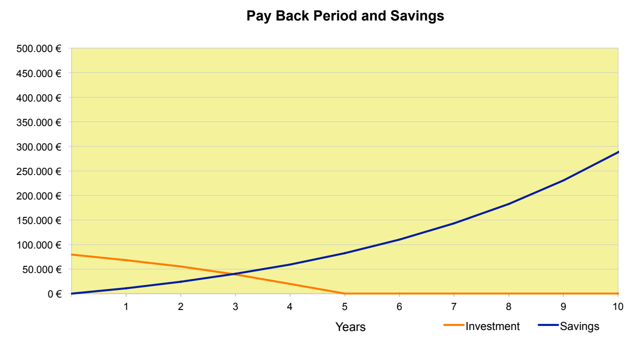
Solar Thermal System - Amortization

Project	Ocean View Hotel - El Gouna		Customer	Three Corners Ocean View Hotel
Solar System	76 m²		Inlet Water	20 °C
Hot Water demand	6,32	m³/day	Hot Water	45 °C
			Fuel LHV	1,00 kWh/kWh Electric
Solar Energy	87.130	kWh/year		
Energy Savings	96.811	kWh/year		
Savings 1st Year	11.080	EUR		
Average Savings over 5 Years	16.491	EUR/year		
Investment for Solar System	79.500	EUR		
Annual Rate of Return on Investment	20%			
Return of Investment within	5,0 years			



Savings based on yearly fuel price increases:

Average Fuel Price Increase 20% /year

	Installation	1. year	2. year	3. year	4. year	5. year	6. year	7. year	8. year	9. year	10. year
Fuel Savings	-	11.080 €	13.296 €	15.955 €	19.146 €	22.976 €	27.571 €	33.085 €	39.702 €	47.642 €	57.171 €
Accumulated Savings	**-**	**11.080 €**	**24.376 €**	**40.331 €**	**59.478 €**	**82.453 €**	**110.024 €**	**143.109 €**	**182.810 €**	**230.452 €**	**287.623 €**
Investment	**79.500 €**	**68.420 €**	**55.124 €**	**39.169 €**	**20.022 €**						

CALCULATIONS BASED ON:

1) Fuel price increase within period of amortization per year	20%
2) Energy costs in the first year of operation [EUR/kWh]	0,114
3) Energy efficiency of client's existing hot water system	90%

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Figure 285: Amortization plan to replace the old solar thermal system of the 79-room building

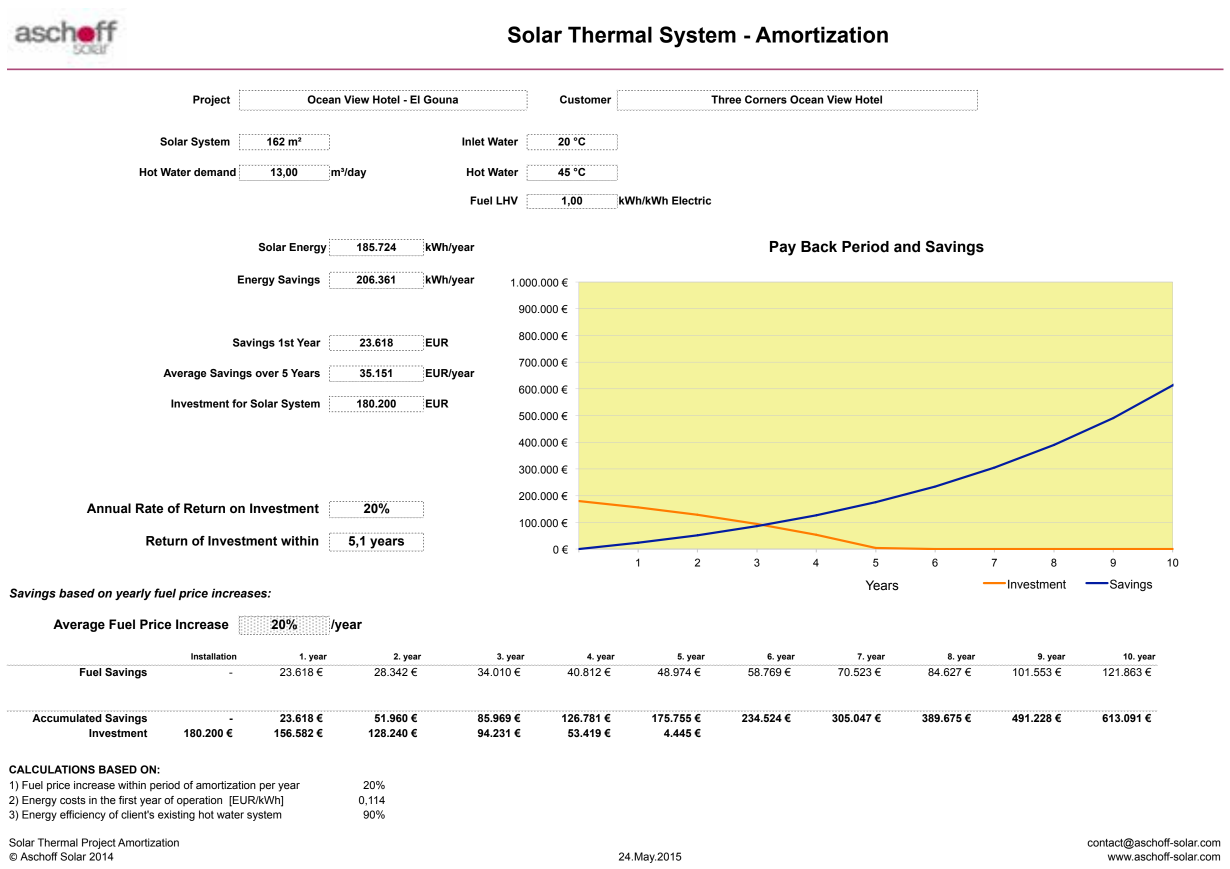


Figure 286: Amortization plan of a new solar thermal system of the 155-room building

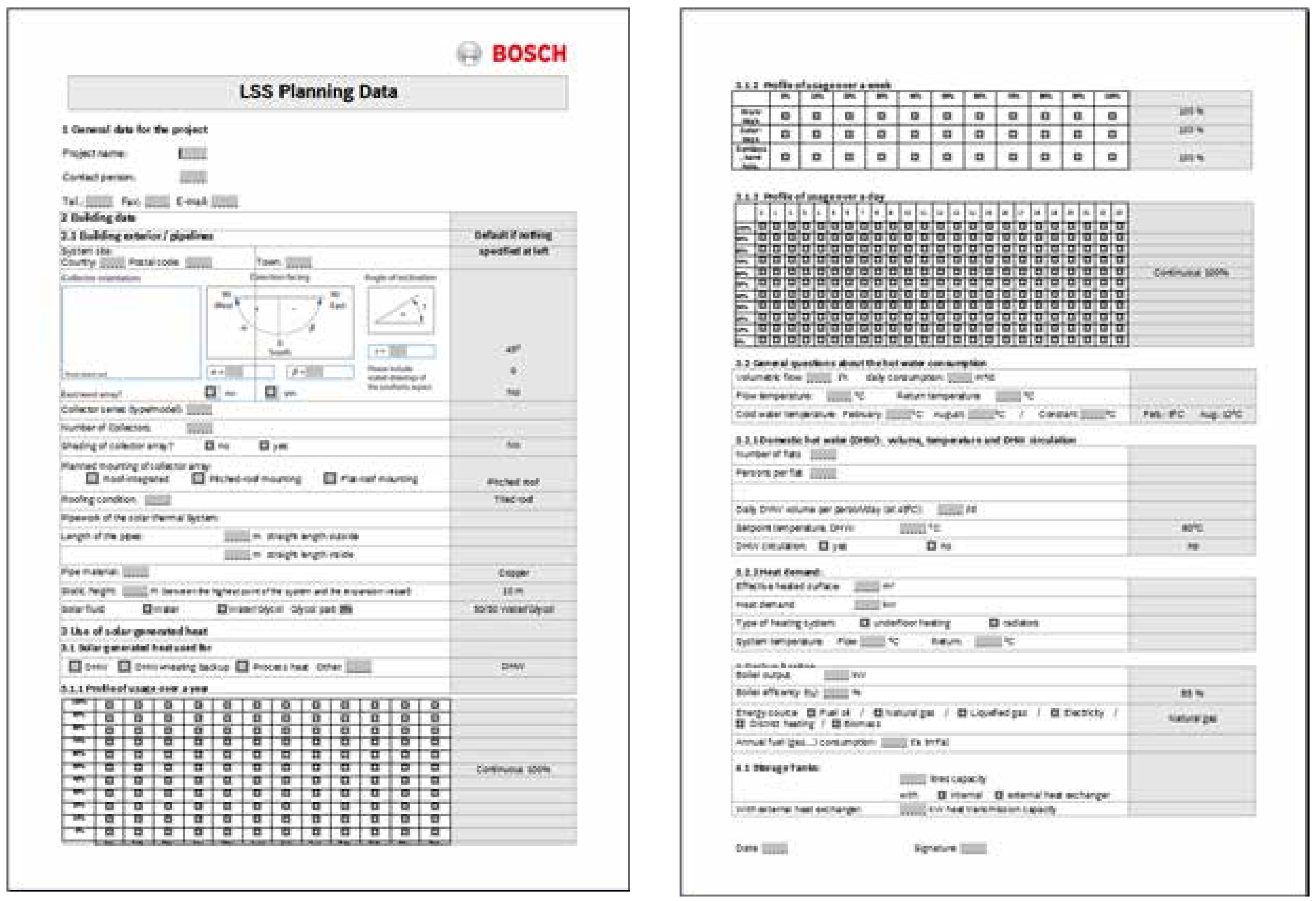


Figure 287: A filled out planning datasheet.

1. Replacing the existing solar thermal system for the 79-room building

When sizing the collector array for the hotel sector, it is beneficial to use reference values for the estimated collector area measured for an economically optimal size. Table 20 gives an idea for reference values in hotels.

Table 22: Collector area according to solar fraction

Application	DHW (Domestic Hot Water)
Solar coverage SC (solar fraction)	60-80%
Collector array	1m² / 70-120 litre DHW per day

Domestic hot water demand	
Average daily consumption:	6,323 m³
Desired temperature:	45°C
Consumption profile:	El Gouna
Cold water temperature February:	23.5°C
August:	27°C
Circulation:	Yes

According to table 22, the collector array should be designed between:

6,323 l/d / 70 l/d × m² = 90 m² and between

6,323 l/d / 120 l/d × m² = 53 m²

→ Chosen collector array: 76m² = 30 psc. Buderus SKS5.0, each 2.55 m² gross area

The results for the DHW lead to a very high solar fraction of approx. 90%, needing a 76 m² roof installation (Figure 288). The hotel management preferred a large solar fraction, to cover most of their energy demand with the solar system, especially during the summer months. Based on this system design, the electric heaters can be switched off most of the year, resulting in high energy savings and a fast payback period. The hydraulic connection of the collectors on the roof varies according to the roof design and technical specification of the collectors. For this system solution, 3 rows with each 10 collectors were chosen (figure 290).

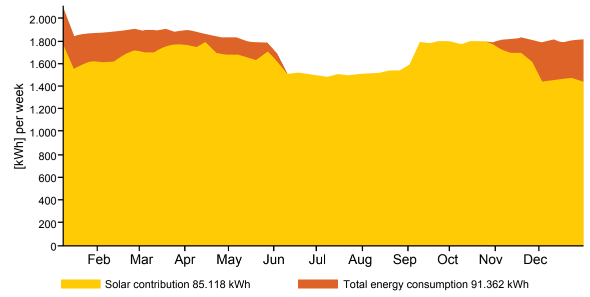


Figure 288: Total energy consumption of the hotel for DHW with a very high solar fraction (93.2% of DHW of a solar system with 76m² on the roof).

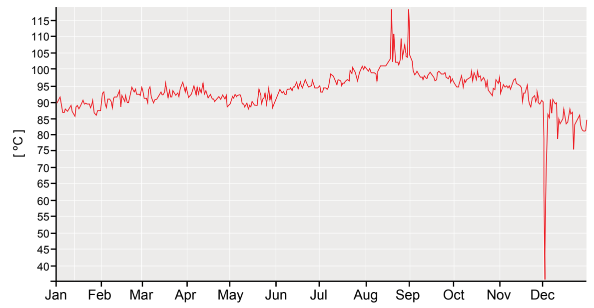


Figure 289: Maximum collector temperature over the year. The high solar fraction leads to high temperatures in the collector. A small change of the consumption per day can lead to stagnation in the collector field.

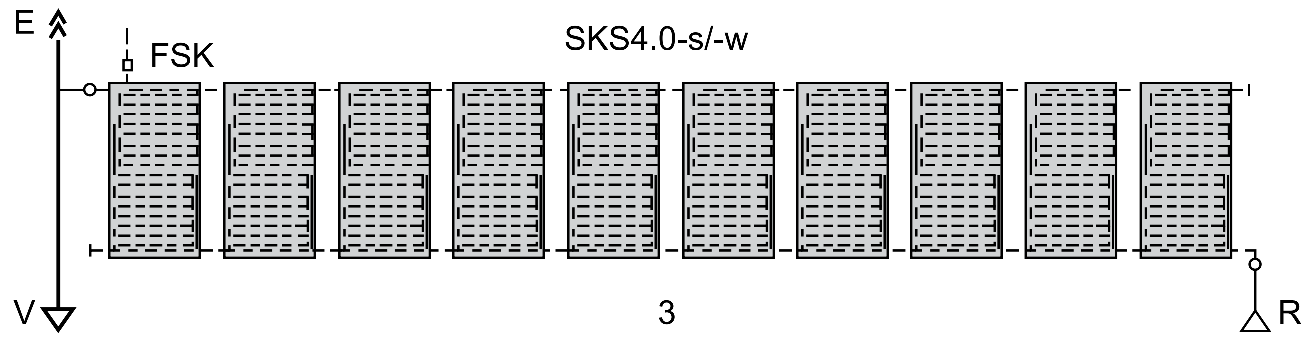


Figure 290: Connecting a row of collectors (here: Buderus SKS4.0/5.0)

The hydraulic system for the 79-room building

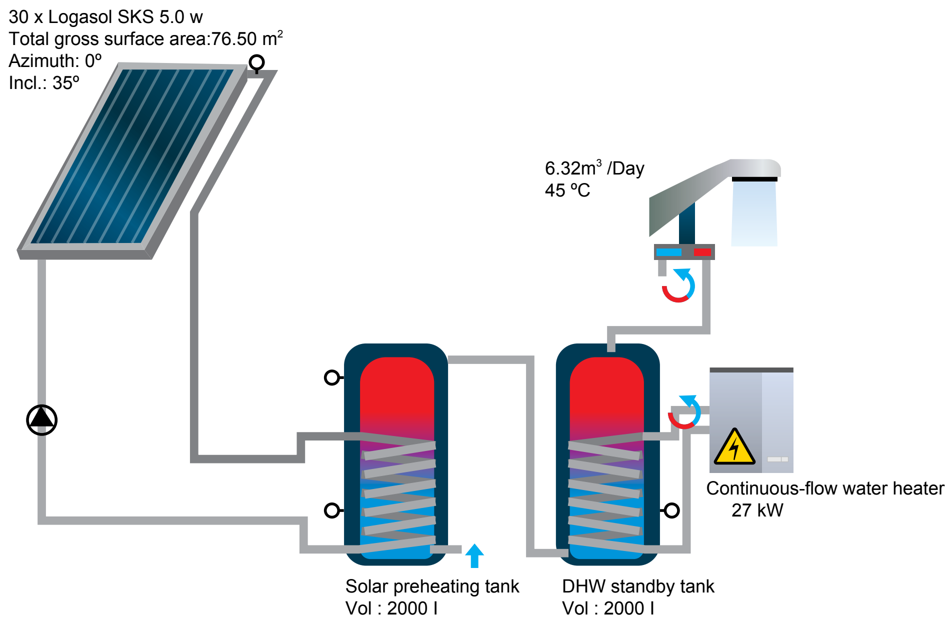


Figure 291: Typical hydraulic system for a solar thermal system for DHW

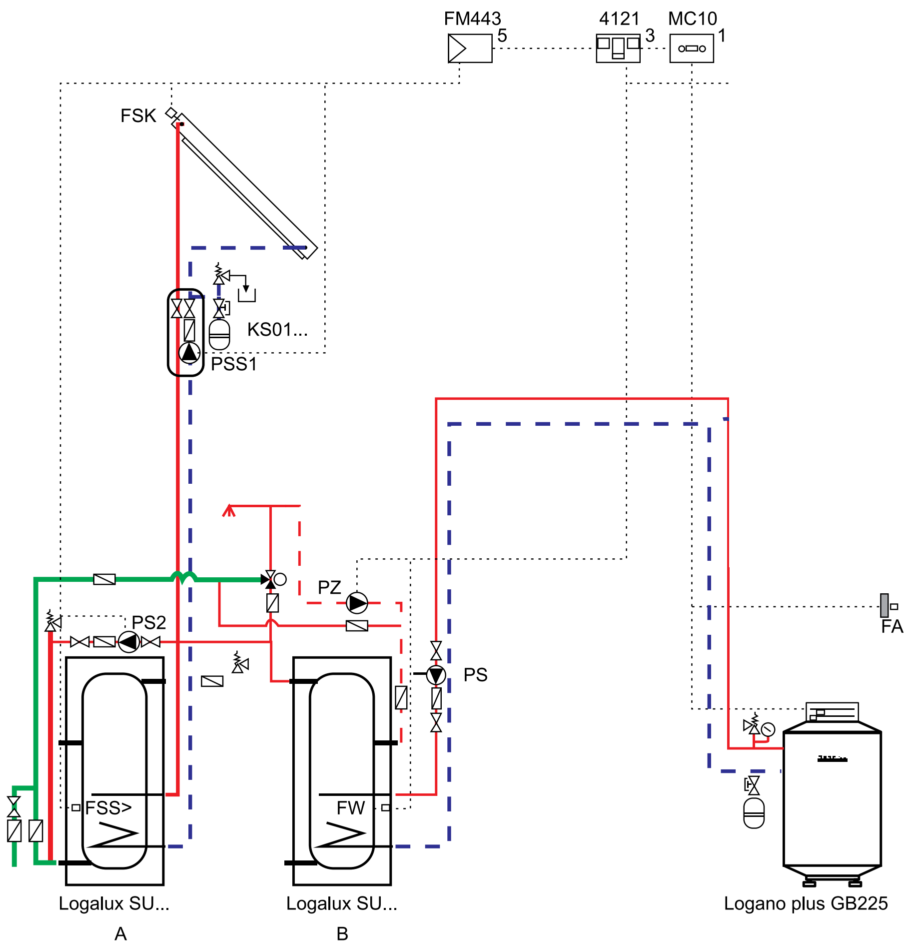


Figure 292: Example of a 2-cylinder system with a preheating cylinder filled with potable water and a standby cylinder to control for transfer and thermal disinfection circuits in accordance with the water hygiene regulations[1].

A Preheating cylinder: System section supplied by solar (preheating stage)

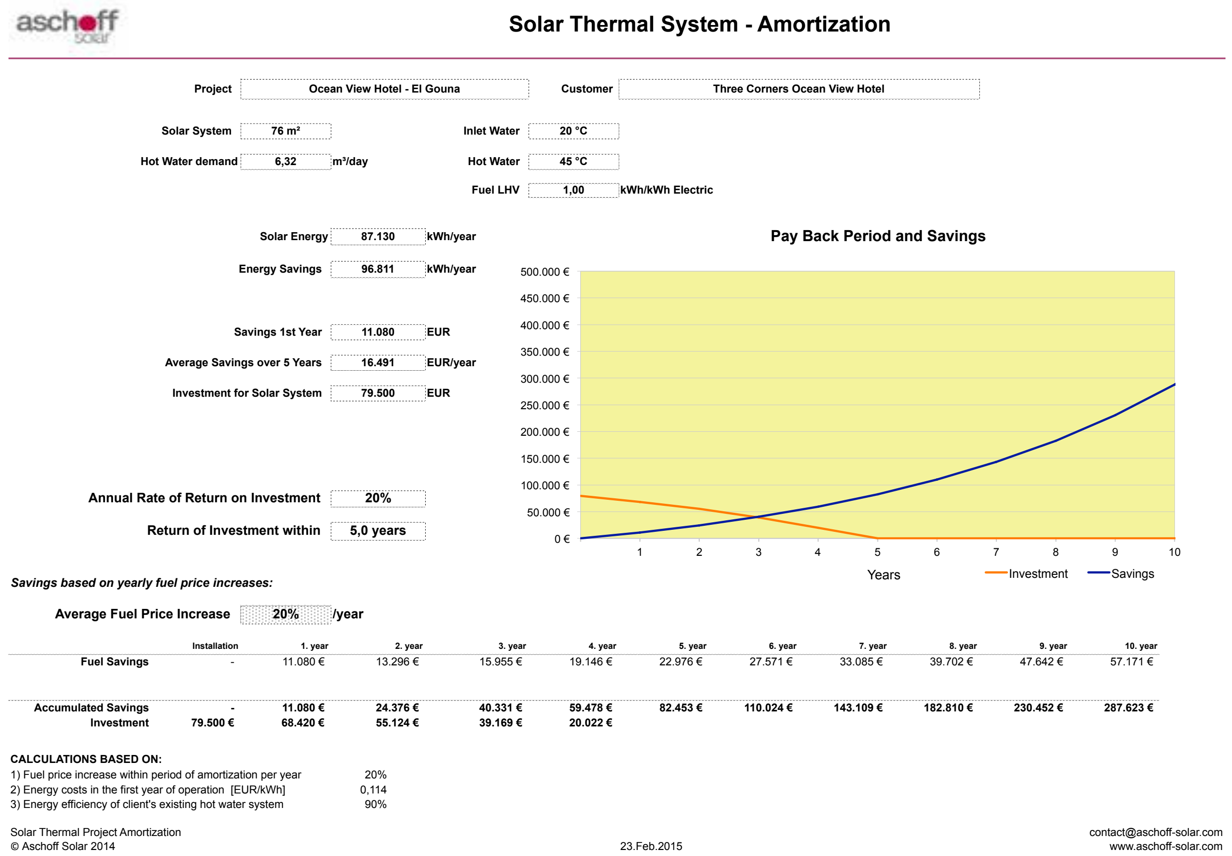
B Standby cylinder

[1]This circuit diagram is only a schematic illustration and provides a non-binding indication of a possible hydraulic circuit. Install safety equipment in accordance with applicable standards and local regulations.

Results of the annual simulation:

Installed collector power: 53.55 kW
Installed solar surface area (gross): 76.5 m²
Irradiation on to collector surface (active): 174.50 MWh → 2,585.13 kWh/m²
Energy delivered by collectors: 93.63 MWh → 1,387.14 kWh/m²
Energy delivered by collector loop: 86.95 MWh → 1,288.18 kWh/m²
DHW heating energy supply: 53.15 MWh
Solar contribution to DHW: 85.12 MWh
Energy from auxiliary heating: 6.2 MWh
Electricity savings: 100,138.5 kWh
CO2 emissions avoided: 66,692.25 kg
DHW solar fraction: 93.2 %

System efficiency: 48.8 %



Solar Thermal System - Amortization

Project: Ocean View Hotel - El Gouna
Customer: Three Corners Ocean View Hotel

Solar System: 76 m²
Hot Water demand: 6,32 m³/day
Inlet Water: 20 °C
Hot Water: 45 °C
Fuel LHV: 1,00 kWh/kWh Electric

Solar Energy: 87.130 kWh/year
Energy Savings: 96.811 kWh/year

Savings 1st Year: 11.080 EUR
Average Savings over 5 Years: 16.491 EUR/year
Investment for Solar System: 79.500 EUR

Annual Rate of Return on Investment: 20%
Return of Investment within: 5,0 years

Savings based on yearly fuel price increases:

Average Fuel Price Increase: 20% /year

	Installation	1. year	2. year	3. year	4. year	5. year	6. year	7. year	8. year	9. year	10. year
Fuel Savings	-	11.080 €	13.296 €	15.955 €	19.146 €	22.976 €	27.571 €	33.085 €	39.702 €	47.642 €	57.171 €
Accumulated Savings	-	11.080 €	24.376 €	40.331 €	59.478 €	82.453 €	110.024 €	143.109 €	182.810 €	230.452 €	287.623 €
Investment	79.500 €	68.420 €	55.124 €	39.169 €	20.022 €						

CALCULATIONS BASED ON:
1) Fuel price increase within period of amortization per year: 20%
2) Energy costs in the first year of operation [EUR/kWh]: 0,114
3) Energy efficiency of client's existing hot water system: 90%

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Figure 293: Amortization plan to replace the old solar thermal system of the 79-room building.

2. Installing a new solar thermal system for the 155-room building and swimming pool

To size the collector array, the following reference values serve for a rough estimate of an economically sized collector area:

Application Domestic hot water
Solar coverage SC (solar fraction) 60-80%
Collector array 1 m²/70-120 litre DHW per day

Domestic hot water demand:

Average daily consumption:	13 m³
Desired temperature:	45°C
Consumption profile:	El Gouna
Cold water temperature	
February:	23.5°C
August:	27°C
Circulation:	Yes
Outdoor pool	
Pool area:	300 m²
Auxiliary heating:	No

According to the reference values, the collector array should be designed between:

13,000 → l/d ⁄ 70 l/d × m² = 185 m² and between

13,000 → l/d ⁄ 120 l/d × m² = 108 m²

Chosen collector array: 163.2 m² = 64 psc. Buderus SKS5.0, each 2.55 m² gross area

Controller strategy

Depending on the controller strategy, a large collector field will lead to a high solar fraction of around 95%. The controller of the solar system is able to run the system in two different ways:

- Priority on DHW: If the temperature of the collector is higher than the temperature in the DHW, the system will always load the DHW tank first. If the tank reaches his maximum temperature, usually between 45-60°C, the pool will be loaded using solar energy only.

- Priority on the pool: If the temperature of the collector is higher than the temperature in the pool, the system will always load the pool first. If the pool reaches his maximum temperature, usually between 22-28°C, the DHW tank will be loaded using solar energy only.

The first option leads to a very high solar fraction for DHW, whereas the second option leads to a higher output of the collector field or system efficiency due to the lower temperatures in the solar system. In consultation with the owner of the hotel, option 1 was chosen.

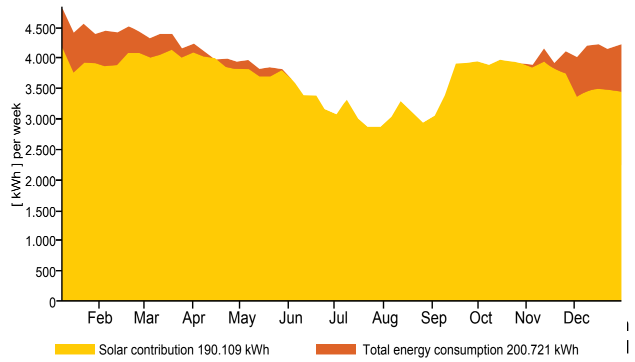


Figure 294: Total energy consumption of the hotel for DHW with a very high solar fraction (93.6% of DHW of a solar system with a 163.2m² collector field on the roof).

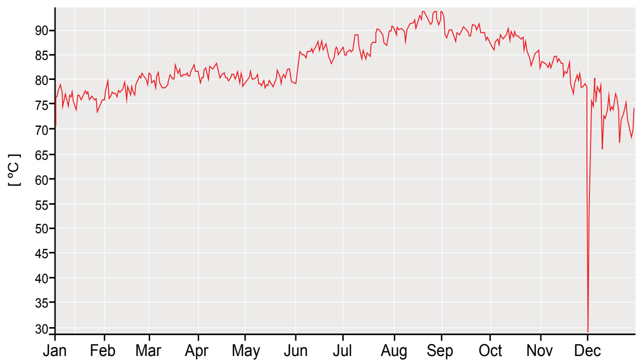


Figure 295: Maximum collector temperature over the year. The controller option 1 (priority on DHW) leads to higher temperatures in the collector. Yet, there is no danger of stagnation, because the overcapacity from the collector field will load the swimming pool.

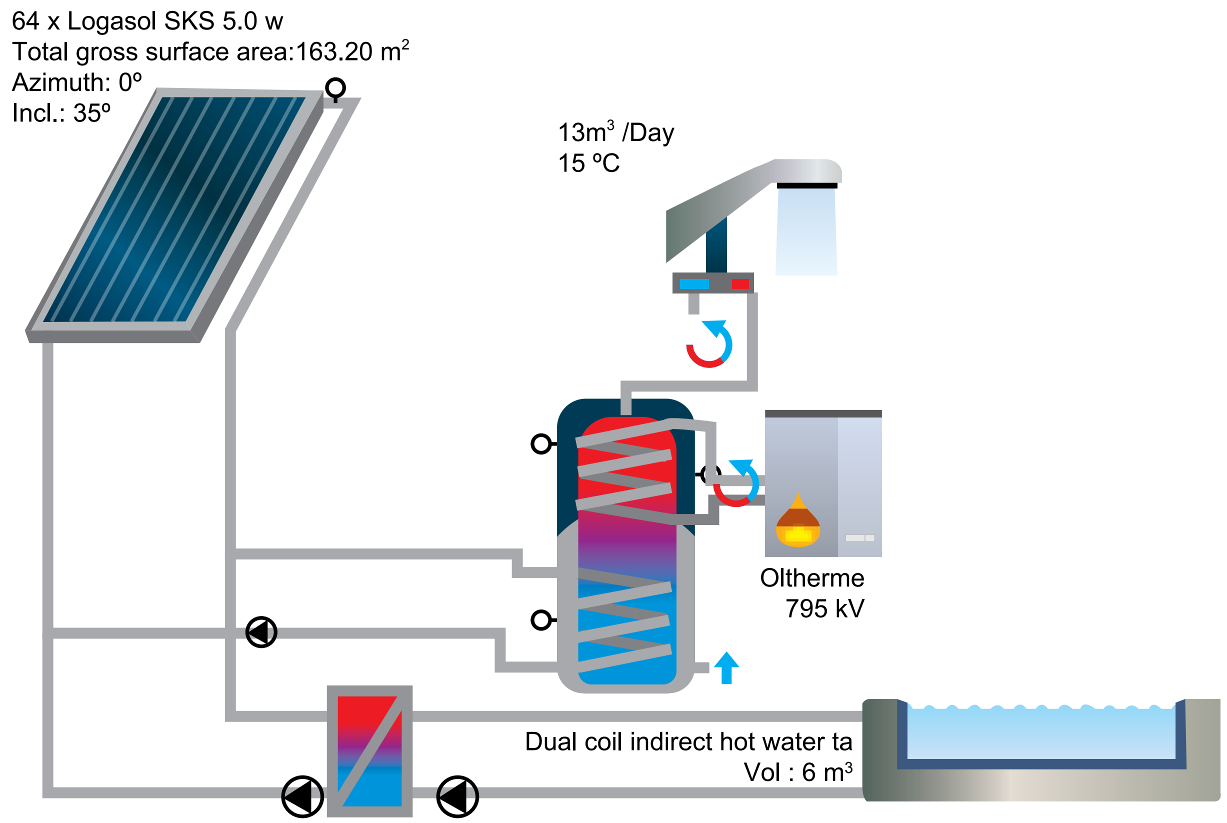


Figure 296: Typical hydraulic system for a solar thermal system for DHW and pool heating

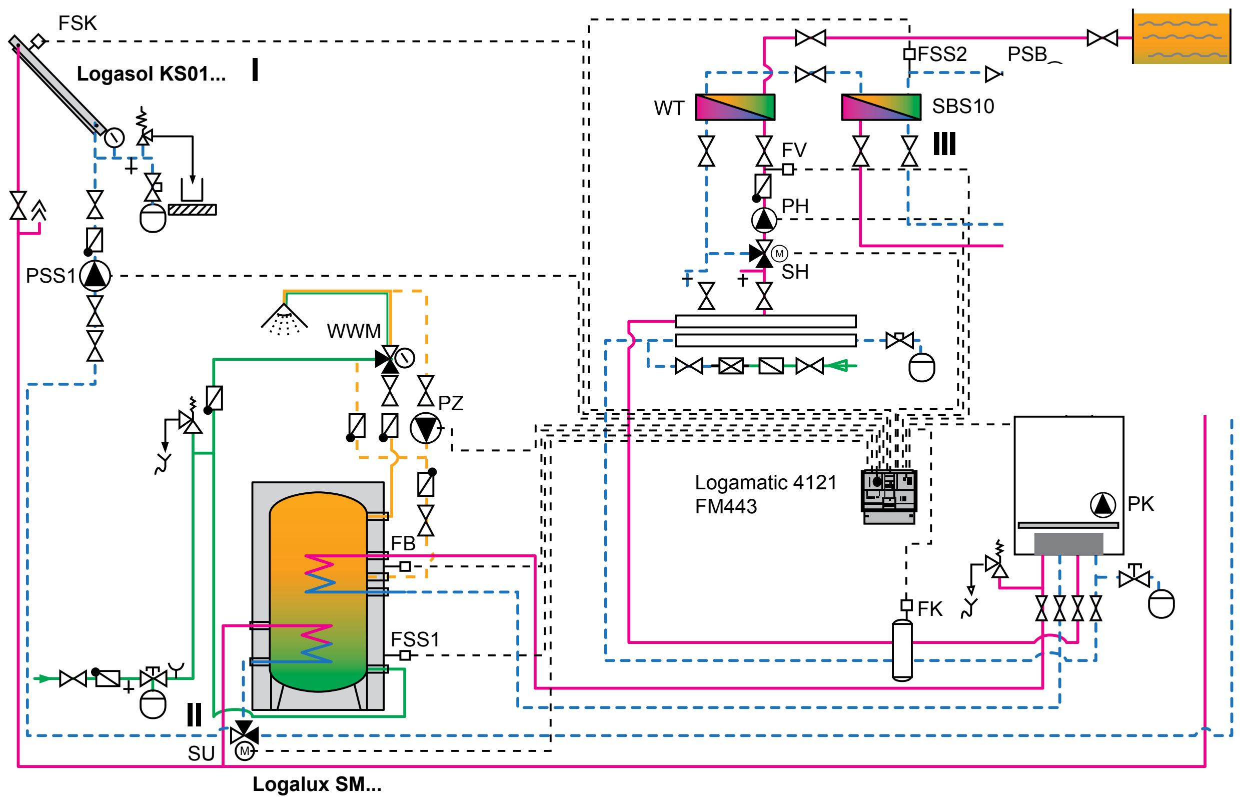


Figure 297: Solar DHW heating and swimming pool heating with a gas or diesel boiler and a DHW cylinder (here: Buderus system)[2].

[2] This circuit diagram is only a schematic illustration and provides a non-binding indication of a possible hydraulic circuit. Install safety equipment in accordance with applicable standards and local regulations.

Solar circuit

The first consumer is heated according to the temperature difference between FSK and FSS1. If the 1st consumer reaches is heating maximum, the 2nd consumer, the swimming pool, is heated via the SBS10 swimming pool heat exchanger, according to the temperature difference between FSK and FSS2. The heat status of the 1st consumer should be checked at brief intervals.

DHW reheating

The boiler reheats the standby section of the solar cylinder whenever required, according to the FB temperature sensor.

Swimming pool reheating

The boiler heats the swimming pool via a heating circuit with a heat exchanger (WT).

Results of the annual simulation:

Installed collector power: 114.24 kW

Installed solar surface area (gross): 163.2 m²

Irradiation on to collector surface (active): 372.26 MWh →2,585.13 kWh/m²

Energy delivered by collectors: 205.95 MWh →1,430.22 kWh/m²

Energy delivered by collector loop: 191.86 MWh →1,332.39 kWh/m²

DHW heating energy supply: 109.33 MWh

Solar contribution to DHW: 157.78 MWh

Energy swimming pool solar system: 34.09 MWh

Energy from auxiliary heating: 10.6 MWh

Fuel oil savings: 34.3 m³

CO_2 emissions avoided: 91,241.93 kg

DHW solar fraction: 24.83 °C

Average swimming pool temp: 57.0% of operating hours

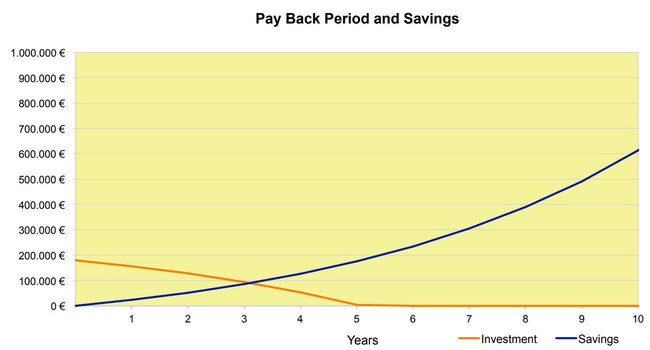
Pool temperature above 23 °C: 51.1%

The hydraulic system for the 155-room building

Solar Thermal System - Amortization

Project	Ocean View Hotel - El Gouna	Customer	Three Corners Ocean View Hotel
Solar System	162 m²	Inlet Water	20 °C
Hot Water demand	13,00 m³/day	Hot Water	45 °C
		Fuel LHV	1,00 kWh/kWh Electric

Solar Energy	185.724	kWh/year
Energy Savings	206.361	kWh/year
Savings 1st Year	23.618	EUR
Average Savings over 5 Years	35.151	EUR/year
Investment for Solar System	180.200	EUR
Annual Rate of Return on Investment	20%	
Return of Investment within	5,1 years	



Savings based on yearly fuel price increases:

Average Fuel Price Increase 20% /year

	Installation	1. year	2. year	3. year	4. year	5. year	6. year	7. year	8. year	9. year	10. year
Fuel Savings	-	23.618 €	28.342 €	34.010 €	40.812 €	48.974 €	58.769 €	70.523 €	84.627 €	101.553 €	121.863 €
Accumulated Savings	**-**	**23.618 €**	**51.960 €**	**85.969 €**	**126.781 €**	**175.755 €**	**234.524 €**	**305.047 €**	**389.675 €**	**491.228 €**	**613.091 €**
Investment	**180.200 €**	**156.582 €**	**128.240 €**	**94.231 €**	**53.419 €**	**4.445 €**					

CALCULATIONS BASED ON:

1) Fuel price increase within period of amortization per year	20%
2) Energy costs in the first year of operation [EUR/kWh]	0,114
3) Energy efficiency of client's existing hot water system	90%

Solar Thermal Project Amortization

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Figure 298: Amortization plan of the new solar thermal system for the 155-room building

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