USE OF RENEWABLE ENERGY SOURCES IN THE WORLD AND ARMENIA

THROUGH INNOVATIONS TO CLEAR TECHNOLOGIES






YEREVAN - 2010

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United States Alumni Association of Armenia

US Embassy, Yerevan, PAS office, USG Alumni Outreach Grant Program

"EcoTeam" - Energy and Environmental Consulting NGO

United Nations Development Program

Global Environment Facility

"Enabling Activities for the Preparation of Armenia's Second National Communication to the UNFCCC" UNDP/GEF Project (2006-2009)

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PREFACE

The English version of brochure is prepared by Artashes Sargsyan, PhD, alumnus of IVLP program with support from United States Alumni Association of Armenia (USAAA) and US Embassy, Yerevan, PAS office, USG Alumni Outreach Grant Program in collaboration with "EcoTeam"-Energy and Environmental consulting NGO and "Enabling Activities for the Preparation of Armenia's Second National Communication to the UNFCCC" UNDP/GEF Project in 2010.

The brochure is recommended by the Chair of "Semiconductor Physics and Microelectronics" of Radiophysics Faculty of the Yerevan State University and the Chair of "Industrial Enterprise Economy, Organization, Planning and Energy" of the Energy Faculty of the Armenian State Engineering University to use in the "Alternative Energy Sources" Subject.

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The Armenian version of brochure was developed by Artashes Sargsyan, PhD (Physico-Mathematical Sciences in the framework of the "Enabling Activities for the Preparation of Armenia's Second National Communication to the UNFCCC" UNDP/GEF Project.

The brochure discusses issues on renewable energy: solar, wind, biomass and geothermal energy, their available resources, the most modern technologies and their application, market development perspectives, regulatory mechanisms, in the context of climate change mitigation. Since there has been significant progress in development of small hydropower plants in Armenia recently, it was considered reasonable to present these issues in a special brochure.

The brochure can be used by students, lecturers, engineers as well as by a large group of readers interested in the advancement of renewable and alternative energy technologies and their possible application in Armenia.

The author expresses his gratitude to UNDP and Project staff in Armenia, in particular, to Armen Martirosyan, Diana Harutyunyan, Aram Ter-Zakaryan, Naira Aslanyan - for their professional advises and assistance in publication of the brochure, Julieta Arustamyan – for assistance in editing of Armenian version, as well as Ferdinand Gasparyan, Doctor of Physico-Mathematical Sciences, YSU professor - for review, and Gunnar Olesen, INFORSE-Europe network Coordinator - for resources provided.

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RENEWABLE ENERGY USE IN THE WORLD AND IN ARMENIA
THROUGH INNOVATIONS TOWARDS CLEAN TECHNOLOGIES

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CHAPTER 1 CLIMATE CHANGE AND RENEWABLE ENERGY RESOURCES

The current way of energy production and consumption is not compatible with the principles of Sustainable Development (SD). On the one side, 2 billion people have no access to electricity or commercial fuel (natural gas, liquid or solid fuels) and use traditional fuel (fuel wood) to prepare food and to heat the homes. On the other side, energy consumption continues to grow. Also adverse influence of energy production processes and combustion of transport fuel on environment grow, causing the raise of greenhouse gas (GHG) emissions and global warming, acids rains, growth of air, water and earth pollution, etc [1.2]. In accordance with the forecasts, concentration of CO_2 will grow from 367 mln^{-1} at present to 490-1260 mln^{-1} in 2100. In other words, CO_2 concentration in the air will rise by 75-350% as compared with the level as of 1850. As a consequence of CO_2 concentration raise it is forecasted that the temperature of the Earth atmosphere near surface will rise within 1.4-5.8^{0}C by 2010 [2].

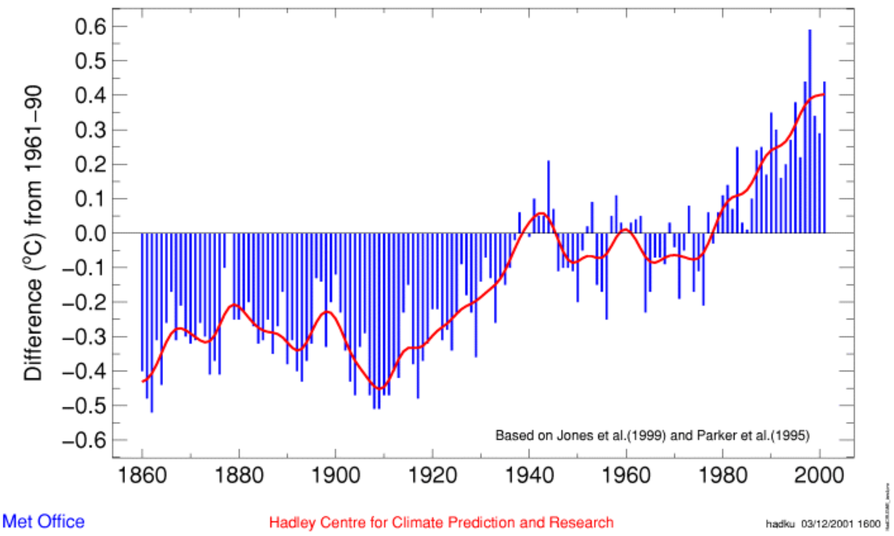


Fig. 1.1. Global average near-surface temperatures annual anomalies, 1860-2001

1.1 Energy Production and Consumption

Nowadays, the most part of consumed energy is produced from fossil fuels (coal, oil, natural gas), which were formed several million years ago as a result of decay of remnants of animals and plants under conditions of high pressure and temperatures. Fossil fuels are consumed at greater rate than formed now in Earth layers under heat and pressure and will disappear completely after some definite time period in the future. For that reason they are called “Non renewable energy resources”. Nuclear fuel – uranium has a specific place among “Non renewable energy resources”. Its resources can be exhausted in a hundred years, but in breeder reactors it can be multiplied and lasts much longer. Though GHG emissions from Nuclear Power Plants (NPP) are close to zero, nevertheless the high risks of NPPs limit their development. To meet ever growing demands of mankind in energy it is required to develop renewable energy resources: solar, wind, water flows, biomass, and geothermal. The impacts on environment are significantly less from renewable energy sources compared with impacts caused by combustion of fossil fuels. Data on installed capacities of RES worldwide for 2004-2008 are brought in Table 1 [6].

Energy consumption worldwide is around 10 billion tons of coal equivalents per year. The share of oil in total consumption is 40%, share of gas and coil – 50%. In 2008, Total Primary Energy Supply (TPES) was 12,267.38 Mtoe, and Total final consumption (TFC) was 8,248.41Mtoe [45].

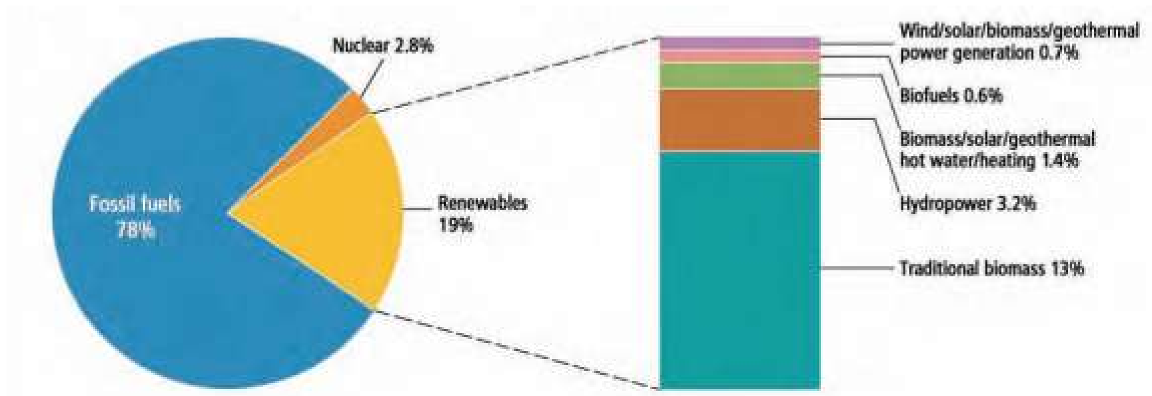


Fig. 1.2. Renewable Energy Share in Total Final Energy Consumption in 2008 [6]

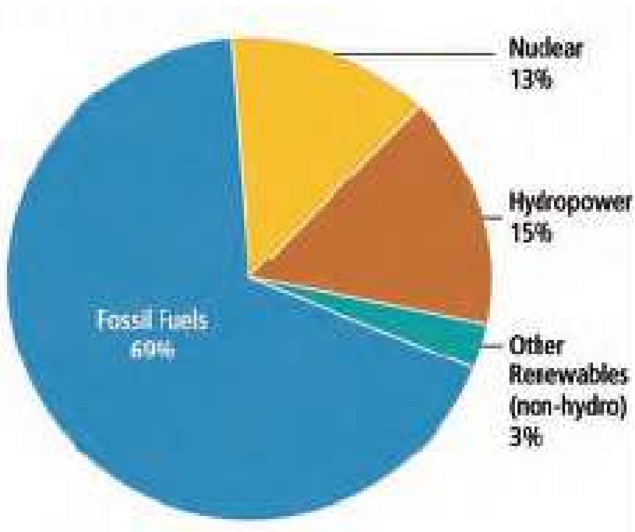


Fig. 1.3. Share of global electricity from renewable energy in 2008 [6]

Global warming and acid rains caused as a result of fossil fuel combustion have the greatest impacts on environment and have global or trans-boundary influence.

1.2 Climate Change Issues

Climate change or global warming is the gradual increase of air temperature near surface of the Earth. CO_2 is the most important of GHG gases. Amount of CO_2 emissions that arise from fossil fuel combustion totals 80% of total amount of CO_2 emission caused by anthropogenic activities. In accordance with the scale of importance CH_4 takes the second place after CO_2, and N_2O – the third place. Global warming potential (GWP) of GHG is calculated as per CO_2 equivalent and for three most important gases it has the following values: $CO_2 = 1$, $CH_4 = 21$, $N_2O = 310$ (see The Third Assessment Report (TAR) of the International Panel on Climate Change (IPCC), 2001) [2]. That means that N_2O has the largest specific impact among above mentioned GHG.

According to the Forth Assessment Report (AR4) of IPCC (2007) Global warming potential for three GHG is equal to 1 for CO_2, 25 for CH_4 and 298 for N_2O, but while preparing national communication the values for GWP are used as they were adopted in 1995 [2].

Combustion of different types of fossil fuels causes different amounts of CO_2 emissions for each unit of energy produced. For coal, oil, and gas corresponding amounts of CO_2 emissions are

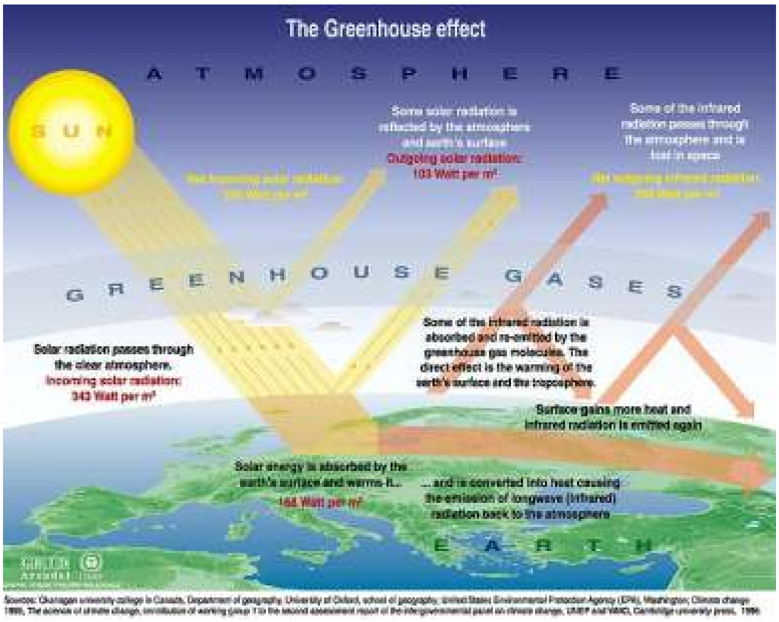


Fig. 1.4. Formation of the Greenhouse effect

expressed by the following ratio: 2:1.5:1. This is the main reason that in spite of significantly greater amounts of coal resources, it is encouraged to switch from coal to natural gas.

In addition to great amounts of CO_2 emissions in the atmosphere as a result of forest logging and fires, also CO2 absorbing capacity of forests is reduced.

1.3 Acid Rains

On pH scale conventional rain has value of 5.6. Acid rains are formed when sulfur dioxide (SO_2) and nitrogen oxides (NOx) emitted in the atmosphere as a result of fossil fuel combustion, are transformed in appropriate acids through chemical reactions in the presence of water vapors. Subsequent rains became a little acid, i.e. their pH became less than 5.6.

Sulfur dioxide emissions from volcanoes, swamps, and decaying plants also contribute to formation of acid rains. It would be appropriate to mention that 90% of sulfur and 95% of nitrogen emissions in Northern America and Europe are of anthropogenic origin.

Acid rains are dangerous for plant life, and in some cases can seriously affect on forests, cause erosion of buildings and metallic constructions. According to the estimates, the damage to only metallic construction is around 2 billion USD per year.

Acid rains cause damage to soil, pollute lakes and seas, air. Water, food, and air polluted by acid rains are dangerous for man health.

1.4 Climate Change Issues in Armenia

Armenia ratified UN Framework Convention on Climate Change (UNFCCC) in 1993 and Kyoto Protocol in 2003. Armenia, as a developing country not included in the Annex I of the UNFCCC, has no quantitative obligations for greenhouse gas emission reduction. However, it undertakes voluntary obligations on the limitation of GHG emissions, with assistance of developed countries, within the frames of corresponding mechanisms of UNFCCC.

Armenia presented the First National Communication on Climate Change to UNFCCC in 1998. It includes national cadastre of greenhouse gases, forecasts of GHG emission till 2010, as well as estimates of impact of global climate change on the natural ecosystems, human health and economy of Armenia.

Following its independence, Armenia's annual greenhouse gas emissions fell sharply from 24400 Gg in 1990 to just 4800 Gg in 1995 as a result of the fuel shortage and rapid industrial decline. Currently, annual CO_2-eq emissions per capita are around 0.0015 Gg CO_2, i.e. are equal to approximately one-third of average in the world value of CO_2-eq emissions per capita of 0.0043 Gg per capita (see Fig. 1.5).

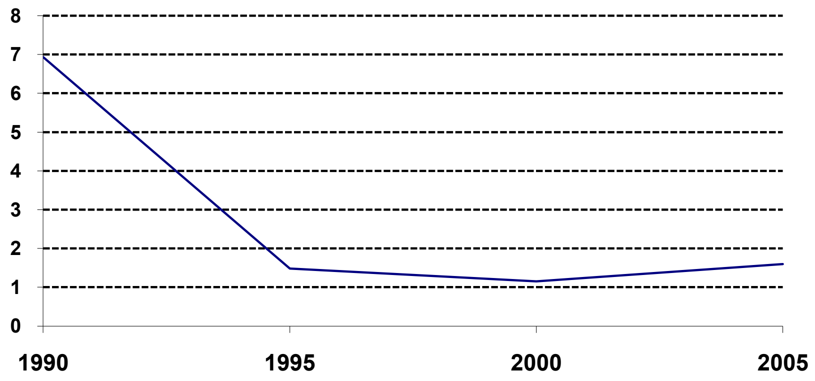


Fig. 1.5. CO_2-eq emissions per capita in Republic of Armenia, Gg/per capita (Source: "Enabling Activities for the Preparation of Armenia's Second National Communication to the UNFCCC" UNDP/GEF Project (2006-2009) (reports).

According to First National Communication on Climate Change of RA to UNFCCC (1988) [18], in case of temperature increase by 2^0C and precipitation decrease by about 10%, the following negative impacts on the ecosystems as well as climate-vulnerable branches of economy are anticipated in 2100: a shift of the landscape-zone borders up the mountain; increase of climate aridity and intensification of desertification processes; reduction of annual river flow by 15 % and increase of evaporation from the surface of Lake Sevan by 13-14%; reduction of the efficiency of plant cultivation by 8-14%; reduction of the pasture area and its productivity by 4-10%.

In 2010 the Second National Communication of RA was presented to UNFCCC. Projections of greenhouse gas emissions for 2005-2020 were done for two scenarios – business-as-usual and rapid stabilization. By 2020, GHG emissions will amount to 61% of their level in 1990 (92% in the case of business-as-usual scenario), the largest share of which (73%) to fall on the energy sector.

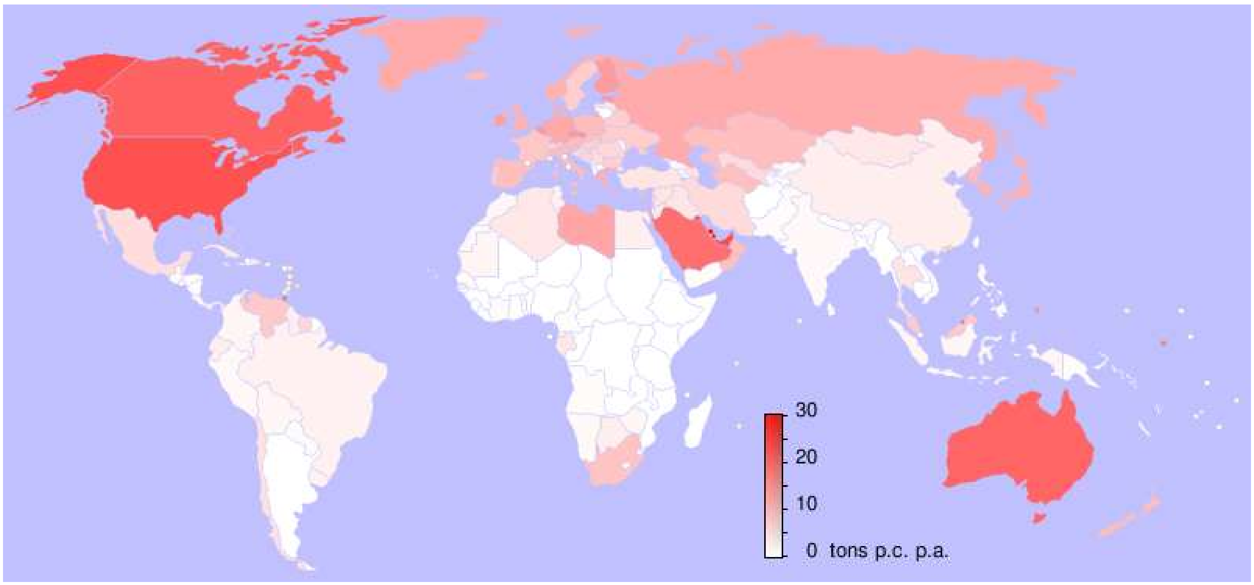


Fig. 1.5. Emissions of CO_2 (tons) per capita per country (2006)

TABLE 1. INSTALLED CAPACITIES OF RES WORLDWIDE FOR 2004-2008 (AS OF END OF EACH YEAR) [6]

Type of RES	Installed Capacities of RES by the End of Each Year					
	2004	2005	2006	2007	2008	2009
Power Generation, GW_{el}						
Large Hydropower Plants	720	750	763	770	860	920
Small Hydropower Plants, <10MW	61		73		85	60
Wind Power Plants	48	59	74	95	121	159
Electricity from Biomass	39		45		52	54
Geothermal Power Plants	8.9		9.5		10	11
Solar PV Plants (off-grid)	2.2		2,7			
Grid-connected PV Plants	1.8	3.5	5.1	7.8	13	21
Solar Thermal Power Plants	0.4		0.4		0.5	0.6
Energy from Ocean Waves and Tides	0.3		0.3		0.3	0.3
Total Installed Capacity of RES (without large HPPs)	*160*	*182*	*207*	*240*	*280*	*306*
Thermal Energy Production for Water and Space Heating, GW_{th}						
Biomass	220		235		250	~270
Solar Thermal Collectors for Water/Space Heating	77	88	105	128	145	180
Geothermal Energy for Heating	13		33		50	~60
Heat Pumps (Geothermal)	15					
Solar Thermal Water Heaters for Households, million	40 *					
Heat Pumps for Buildings Heating, million	2					
Transport Fuel , billion liters/year						
Ethanol Production	31**	33	39	46	67	76
Biodiesel Production	2.2	3.9	6	8	12	17
Rural Energy Production (Stand-Alone Systems)						
Small Biogas Units for Households, million	16					
Small Biomass Gasification Units	n/a					
Small PV-Stations for Households, million	2					
Solar Cookers, million	1					

* Number of households -1600 million.
** Production of gasoline in the words is equal to 1200 billion liters/year.
***360 million households are not connected to grid.

CHAPTER 2 PASSIVE USE OF SOLAR ENERGY

In practice, almost all the energy consumed by mankind has been received from the Sun. The energy of solar radiation has also been accumulated in fossil fuels: coal, oil, and natural gas are residues of plant and animals that received all the energy for their development from solar radiation. Annual energy of solar radiation that reaches the upper border of the Earth atmosphere is around $5.6•10^{24}$J. The Earth's atmosphere reflects back around 35% of this energy ($1.9•10^{24}$ J), and remained part of incident energy is consumed to heat of Earth's surface (around $2.4•10^{24}$ J), to drive evaporation-precipitation cycles (turnarounds) (around $1.3•10^{24}$ J), formation of sea and ocean waves, air flows (winds), and ocean flows (around $1.2•10^{22}$ J).

Solar energy technologies do not necessarily have to be based on a high level of technology. The requirements to solar technologies are on a level sometimes called as intermediate technology. Nevertheless, proper design and optimization of solar energy systems is not easy work and require high level of engineering analysis [25].

2.1 Characteristics of Solar Radiation

Solar radiation is an electromagnetic radiation in the wavelength range of 0.28-3.0 µm near Earth surface (Fig. 3). This range includes invisible for man eye small fraction of ultraviolet radiation within sub range of 0.28-0.38µm (around 2% of solar spectrum), visible light within sub range of 0.38 -0.78 µm (49% of solar spectrum), and invisible infrared portion within sub range of 0.78-3.0 µm (49% of solar spectrum) [1, 42].

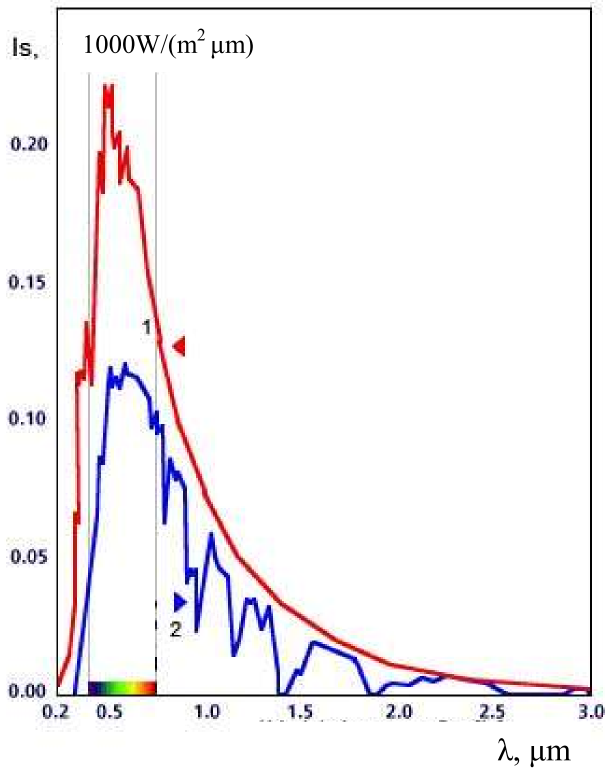


Fig. 2.1. Spectral irradiance of solar light at the upper border of Earth atmosphere (1) and near Earth surface [2]. The peaks on solar spectrum near Earth surface correspond to absorption lines of H_20, CO_2, O_3 atmospheric gases

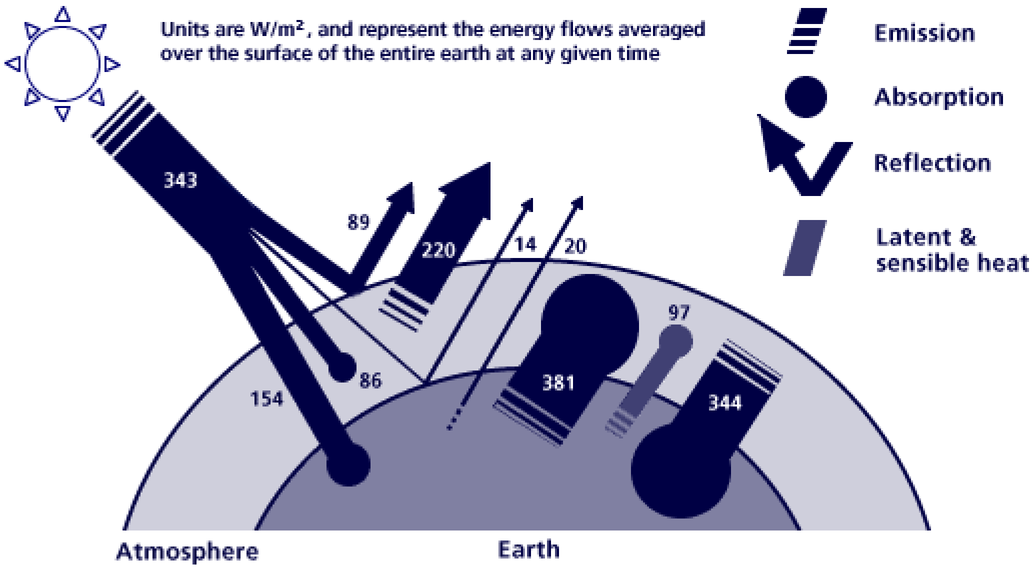


Fig. 2.2. Solar radiation energy flows are averaged over total area of Earth at any time and are measured in W/m^2

2.2 Energy of Solar Radiation Incident on the Earth

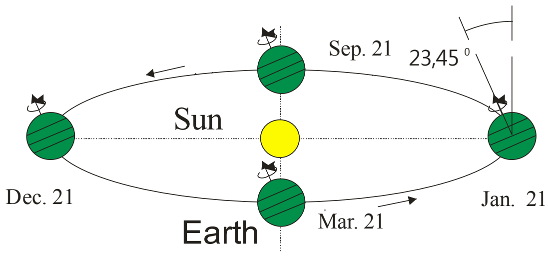


Fig. 2.3. The Earth movement around the Sun along elliptic orbit

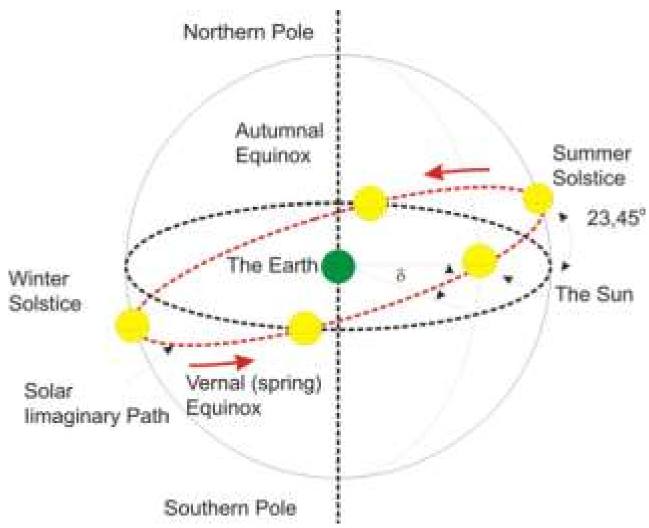


Fig. 2.4. Solar movement on imaginary celestial sphere. Vernal equinox on March 21, autumnal equinox on September 23, δ – declination of the sun` sun angular position in respect to celestial equator at noon. $\delta_0 = 23^0 27' = 23{,}45^0$

The intensity of solar radiation totals $4 \cdot 10^{26}$ W, with that the intensity at the upper border of Earth surface it is $1.78 \cdot 10^{17}$W. Due to absorption by atmospheric gases and scattering at particulate pollutants it is reduced down to $1.2 \cdot 10^{17}$ W near the surface of the Earth. The solar irradiance at the upper border of Earth atmosphere was defined as 1.353 kW/m^2 and is referred to as extraterrestrial or solar constant. Since Earth rotates around the Sun along the elliptic orbit (Fig. 2.3) the distance between the Sun and the Earth is around 149.6 million km on the average and varies by ± 1.7% annually, so solar irradiation depends on inversely as the square of distance. After being transmitted through the Earth atmosphere, solar radiation incident on any surface is composed of the beam (direct) radiation, i.e., solar radiation received from the sun without being scattered by the atmosphere, and of diffuse radiation (solar radiation received from the sun after its direction has been changed by scattering by atmospheric gases, water vapors, particulate pollutants. The sum of the beam and the diffuse radiations is referred to as total solar radiation. The practical applications of such consideration will became clear while calculating parameters of solar collector and solar photovoltaic systems.

Solar irradiation on the unit surface during the day depends on geographical location (latitude), local climate, season of year, tilt angle of unit surface related to horizon.

Due to relative movement of the Sun and the Earth (Fig. 2.3-2.4), the solar irradiation on any considered site varies. At noon the path along which solar radiation reaches the Earth is the shortest, absorption or diffusion of solar radiation is minimal and largest portion of solar energy reaches the Earth.

2.3 Seasonal Variations of Solar Irradiation

The daily solar irradiation that reaches the Earth surface depends on the season of the year. In Northern Europe daily average irradiation is less than 0.8kWh/m^2 in winter, and is more than 4 kWh/m^2 in summer.

2.4 Variations of Solar Irradiation Related with Geographical Location

Solar irradiation that reaches the Earth surface depends on the latitude of the site. The highest values it has for regions near equator. So, average annual total solar irradiation in Central Europe, Central Asia, and Canada is equal to 1000kWh/m^2, in the Mediterranean -1700kWh/m^2, near the equator, in the deserts of Africa and Australia -2200kWh/m^2. Seasonal variations and variations depending on geographical locations of solar irradiation are enough substantial, and this factor shall be taken into the account while developing systems designs (Fig 7).

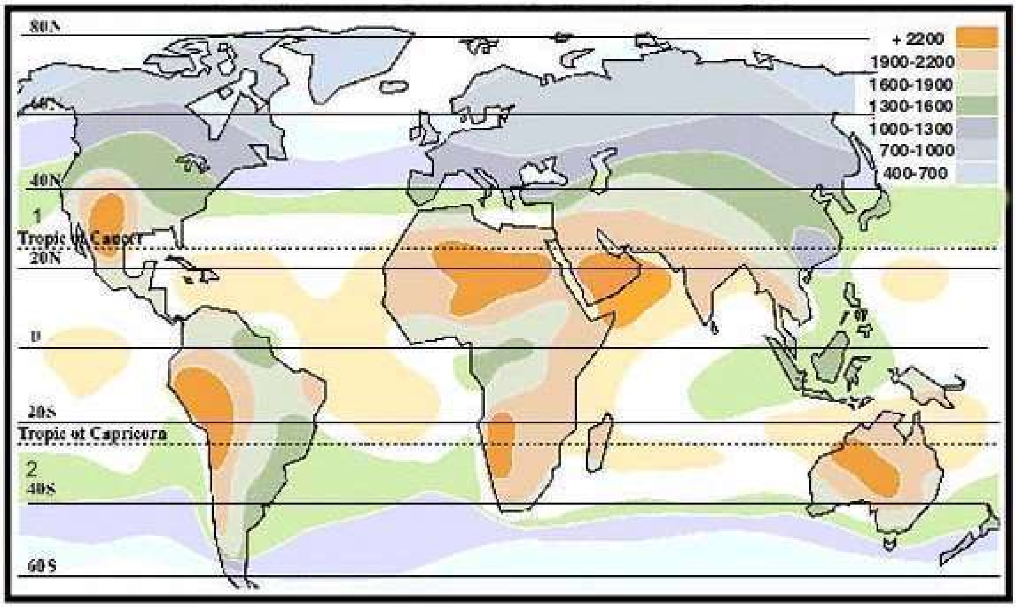


Fig. 2.5. Annual solar irradiation, kWh/m$^{2:}$.
1 – Tropics of Cancer or Northern Tropics (Northern Latitude - 23^{0}27'),
2 – Tropics of Capricorn or Southern Tropics (Southern Latitude - 23027')

2.5 Solar Energy Utilization

Solar energy is converted to useful energy through application of either active or passive solar systems (passive use of solar energy), or both together.

Solar collectors and photovoltaic systems are referred to as active systems. These systems will be considered in details in the following Chapters 3-6.

The systems in which heat transfer is occurred in a natural way through proper design of home or building that maximum amount of solar energy is received is referred to as passive solar systems. In passive solar systems the structures of building are used to accumulate, store and transfer the heat. This definition fits in the best way to simple structures in which the heat is stored in basic elements: in the walls, ceiling, floor: Due to large input in the development such homes by engineer Trombe, the homes are referred to as homes with Trombe walls.

2.6 Principles and Mechanisms of Solar Passive Heating

There exist several important architectural approaches/elements to develop solar passive systems so that up to 15-25% of energy consumed for heating and cooling in households can be saved. These approaches/elements are as follows:

- To provide proper selection of site for the building;
- To use a lot of south-faced windows (in Northern hemisphere) to allow transmittance of solar radiation through the windows during the winter period,
- To use, on the contrary, few windows faced to the East and to the West to limit solar radiation transmittance through the windows during the summer.
- Provide enough interior mass to make temperature changes more smooth;
- Provide proper thermal insulation of the buildings.

Above mentioned approaches shall be applied unanimously.

Fig. 2.6. Passive solar heating

2.7 High-Quality Windows

Use of proper windows is of high importance in all passive systems. The glass pane or other plastic material is transparent for short-wave solar radiation, but is opaque medium for thermal long wave radiation, so due to greenhouse effect the temperature can be increased inside the room. Speaking in more details, window glass is transparent for solar radiation in the range of 0.4-2.5 μm. After solar radiation is transmitted through the window glass it falls on surrounding objects on the other side of windows, is partly absorbed by them, and cause their heating. The spectral curve of thermal radiation of objects at room temperatures is shifted toward long waves as compared with spectrum of solar radiation, and covers range up to 11 μm. The glass is opaque for such long-wave radiation, and this way heat energy is accumulated.

High-quality windows possess the following features:
(a) Two-pane or three-pane thermal insulation,
(b) Glasses with special selective coatings that are transparent for incoming solar radiation, but opaque related to output of thermal long wave radiation
(c) Windows in which space between panes is evacuated or filled with argon
(d) Use of phase changing technologies in which upon switching on to electricity glass or similar surface become opaque or transparent.

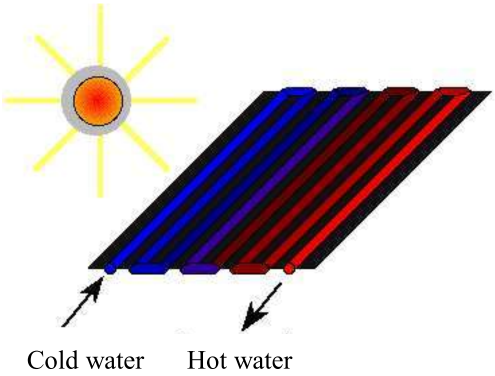
In commercial offices reflective films are often used that are glued to window's glass. This way up it is possible reduce up to 85% of transmitted solar radiation.

It is important while at the stage of design to envisage opportunity of integration of active solar systems (thermal collectors and photoelectric panels). In Northern Hemispheres these systems shall be faced to the South, and in Southern Hemispheres - to the North.

CHAPTER 3 SOLAR HEATERS

3.1 Solar Flat-Plate Water Heaters

The principle of solar heating is known from ancient times. The black surface is warmed under sunlight, and light surface is remained cool. This principle is used in solar water heaters. In 1908, V. Bailey from Carnegie Steel Company (USA) constructed solar collector, in which thermally insulated box and copper coil was used for the first time.



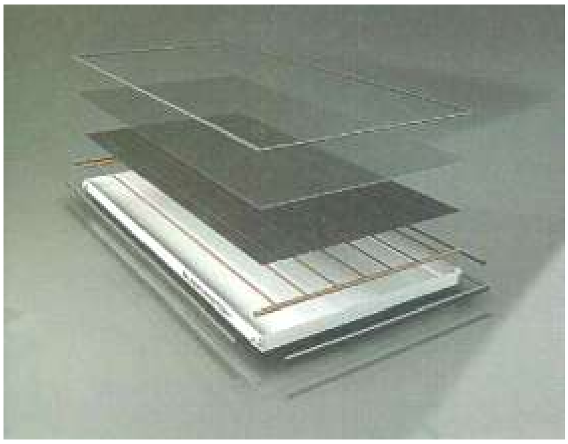


Fig. 3.1. Plane solar collector: a. (in the left) – the principle of operation of solar collector [1], b (in the right) – main elements of modern solar collector [21]

This technology is very close to modern solar collector technologies (thermal siphon systems). Efficiency of solar water heaters increase beginning of 1970th when manufacturers started to utilize tempered glass with low content of iron, new insulation materials and improved durable selective anti-reflection coating. As it is shown in simplified way in Fig. 9, the cool water is warmed when passes through sunlight pipes welded to black sunlight absorbing surface.

In Central Europe and Northern America solar collectors are installed at the angle of more than 50^0 related to horizontal plane to receive maximum heat energy during the winter. To reduce thermal losses solar collector shall be installed as much as possible close to primary heat consumed appliances, for example close to the kitchen or bathroom. In Northern Hemisphere PV panels without trackers are installed faced to the South at the angles to horizontal plane equal to the geographical latitude of the selected site.

3.2 Solar Water Heating Systems

Solar water heaters can vary in sizes and design depending on demand. The solar water heater demonstrated in Fig 9b has the largest application worldwide. The heat is extracted from the collector through working fluid that circulates through the loop. It is carried out using thermosiphon (natural circulation) mechanism (Fig. 10), or by forced circulation (Fig. 11) with application of pump [5].

Instead of water, the antifreeze (ethylene glycol) can be used as a heat transfer medium reducing the possibility of freezing of fluid and removing the necessity to drain out the water from collectors during night times in the winter.

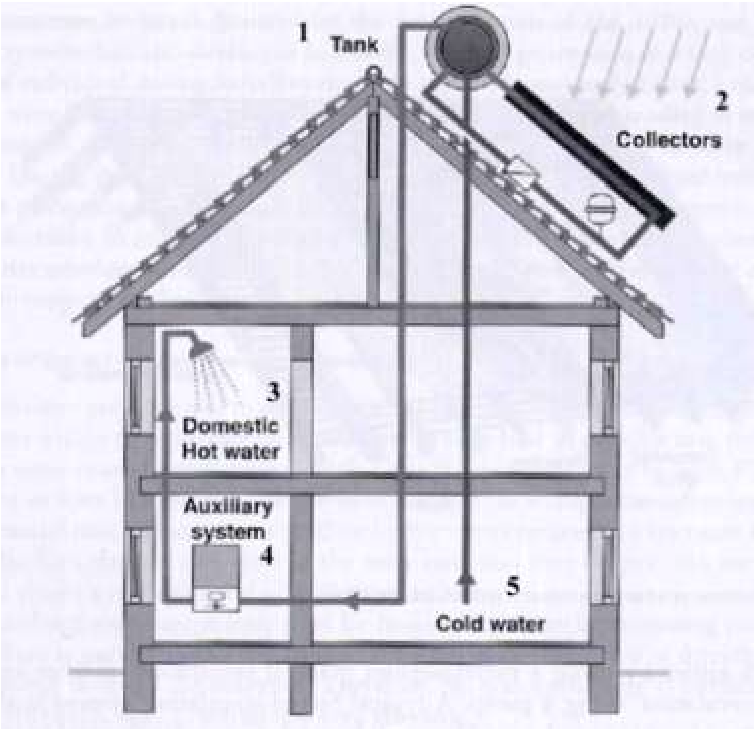


Fig. 3.2. Solar water heating system with thermosiphon circulation: 1-tank, 2-collector, 3 –hot water, 4 – auxiliary system, 5- cold water

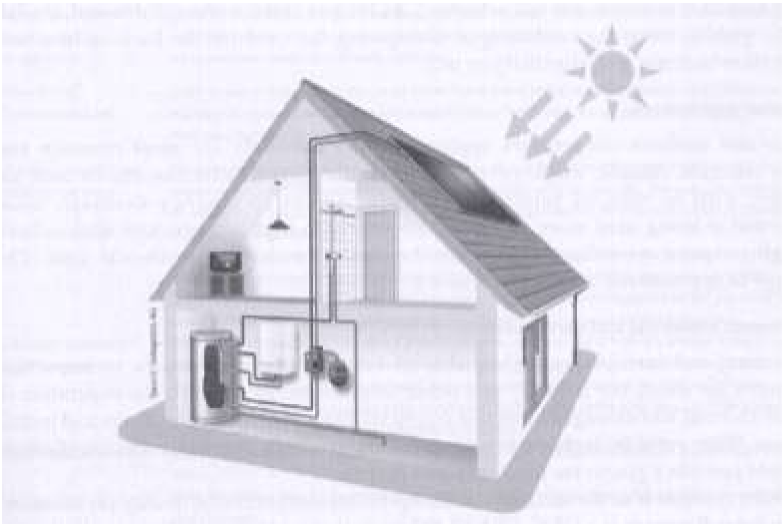


Fig. 3.3. Solar water heating system with forced circulation of fluid

3.3 Traditional and Innovative Approaches in Solar Water Heaters Construction

To provide high thermal conductivity of connection layer between black metal absorber surface of the collector and pipes with fluid, high-quality ultrasonic or laser welding, soldering, mechanical embracing (clasping) and other technologies are used. In Europe, ultrasonic welding is applied by 55% of solar collector manufacturers, laser welding (enough complicated and expensive technology) – by 19%, mechanical embracing (clasping) by 17%, soldering -1%, other - 8% [21]. Black metal absorber surface of the collector and pipes are manufactured from copper, black copper or aluminum, stainless steel. To increase coefficient of absorption these materials are covered with black chrome, chrome-nickel, special selective coating (PVD or other coating technologies) or are painted with black paint. In last case low quality of surface corresponds to low price of collector.

3.4 Cost of Domestic Solar Hot Water Systems

Modern high-quality solar water heaters have operation life time of 20-25 years. The cost of 1 kWh (thermal) is 3-9 Eurocents.

Some features and indicative costs for a few typical solar water heating systems are presented below. German domestic hot water system with $5m^2$ area of flat-plate collectors, with forced circulation by pump, and water storage tank of 300 l is oriented for use in Central Europe and Northern Europe and costs 4500 Euro. It provides annual saving of energy in the amount of 3300kWh. Typical solar hot water systems oriented for use in Eastern Europe (Greek version) includes flat plate solar collectors with total area of $2.4m^2$, water storage tank with capacity of 150l. Its operation is based on thermosiphon principle. The cost of this system is around 700 Euro and it provides annual saving of energy in the amount of 1200kWh [5].

In Israel, typical solar hot water systems with total area of flat-plate collectors with thermosiphon mechanism of fluid circulation and water tank of 150l can be purchased at the price of 360Euro. In this cheap system metal pipes are embraced in absorber system and painted together with sun lightproof paint. Also, conventional window glass is utilized.

High-quality hot water systems in which ultrasonic welding technology, high-quality glass, and absorber surface with selective coating are utilized costs 625 Euro.

Fig. 3.4. Solar air heaters

3.5 Solar Air Heaters

Solar air heating collectors are widely used for heating of buildings, drying of food, etc. Commercial devices operate, for example, by drawing the air through perforated plate of collectors, which serve at the same as outer walls of the design (Fig. 12). They don't have problems with boiling and cooling of heat transfer fluid as it is in case of solar water heaters and which makes the design of last ones more complicated.

3.6 Typical Applications of Solar Heaters

Low-temperature collectors (temperatures lower than 50^0C) with metal or plastic absorber, and medium-temperature collectors (temperatures higher than 50^0C, usually 60-80^0C) are mostly widespread now and have the best indicators of cost/benefit.

High-temperature solar collectors are represented by parabolic trough and parabolic dish collectors, and are used mainly to generate electricity.

3.7 Expected Technological Progress

As to solar energy applications, if appropriate investments are available, technological advances are expected in the following important fields:
(a) Solar air conditioning and refrigerating systems. This area is considered as very prospective as peak demand in air conditioning and refrigerating in summer period coincides with maximum values of solar radiation.

(b) Heat storage. Seasonal storage of heat with reasonable values of cost/benefit will allow using of excess heat energy accumulated during summer period in winter months to meet heat demands.
(c) Solar distillation. While commercial projects have been implemented in this field, solar distillation systems are still too expensive to meet most part of demand. If these systems costs drop down as a result of appropriate technologies development, they will have a lot of applications.

3.8 Solar Collectors with Evacuated Tubes

Fig. 3.5. Solar collector with evacuated tubes

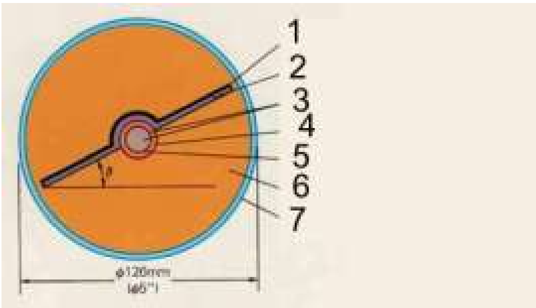
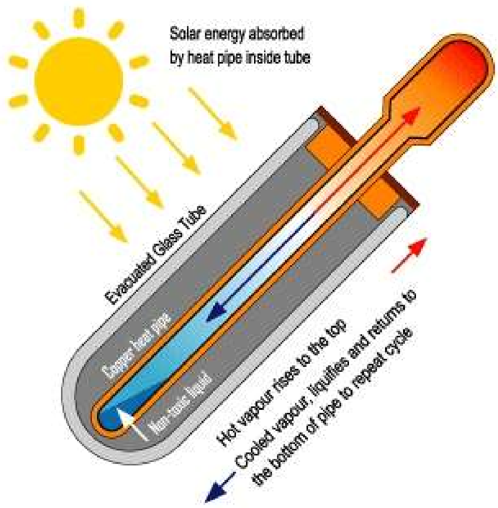


Fig. 3.6. Cross section of evacuated tube [1]
1 – selective coating, 2 – absorbing plate, 3 – heat-transfer fluid, 4 – outer surface of copper pipe, 5 – inner surface of copper pipe, 6 – evacuated space, 7 – glass tube (width of walls is 2mm), diameter of glass tube is126mm (5 inches)

Solar collectors with evacuated tubes (Fig. 13) can effectively operate even during cloudy days [1]. They have more complicated design and, correspondingly, higher prices as compared with flat-plate collectors. This type of collector is used when higher temperatures at the output of collector are required. Incident sunlight is transmitted through outer glass tube 7 (Fig. 14), then through evacuated space 6 and is absorbed by absorbing plate 2 with selective coating 1 and converted to heat. From absorbing plate heat is transferred to fluid circulating in copper pipe which in its turn transfer the heat to manifold receiver and then to water reservoir through heat exchanger. Since air is evacuated from space between outer glass tube and inner tube (it might be glass or copper) so convection and thermal conductivity losses are close to zero. The operation of collectors with evacuated tubes is based on heat pipe mechanism (see box1 below). Additional information is out of our task, and you can find it in special literature.

Box 1



The liquid in the heat pipe changes into vapor which rises to the condenser. When passing through the heat exchanger, the heat is absorbed and the temperature is lowered. The vapor becomes liquid, returns to the base of the heat pipe. The heat pipe is hollow and the space inside, like that of the solar tube, is evacuated. Inside the heat pipe is a small quantity of liquid, such as alcohol or purified water plus special additives. The vacuum enables the liquid to boil (i.e. turn from liquid to vapor) at a much lower temperature than it would at normal atmospheric pressure. When solar radiation falls at the surface of the absorber, the liquid within the heat tube quickly turns to hot vapor and rises to the top of the pipe. Water, or glycol, flows through a manifold and picks up the heat, while the fluid in the heat pipe condenses and flows back down the tube for the process to be repeated.

3.9 Solar Cookers

Though solar cookers are available in developing countries at low price, however, they have limited applications because they cannot be used indoors, in the evening or early morning, when food is usually prepared, or in cloudy days [43].

Box-type solar cooker (Fig. 3.7a) includes well insulated box, with black inner side where black pots with food are placed. Box is insulated by transparent material (one- or two pane-glass, plastic) through which sunlight enters into box and heats the pot. The mechanism of heating is similar to mechanisms occurred in Greenhouse.

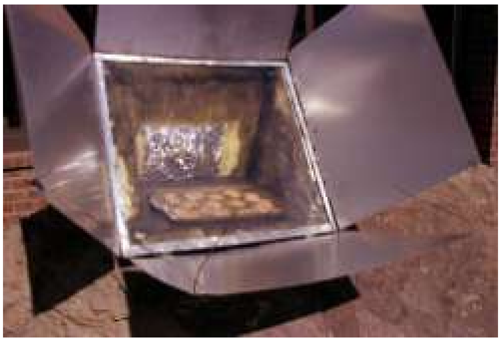


Fig. 3.7a. Box-type solar cooker

Advantages of box-type solar cookers:

- Direct and diffused sunlight is used;
- Lightness and mobility;
- No need to track the sun
- Box can be easily made with use of local materials;
- Cookers are cheap.

Disadvantages of box-type solar cookers:

- Cookers operation is limited to daylight period;
- Moderate temperatures prolong required cooking time;
- Thermal losses in glass or plastic cover

Fig. 3.7b. Parabolic dish solar cooker

In parabolic dish solar cooker (Fig. 3.7b) only direct solar radiation is used and its operation is limited to clear sky days. Parabolic dish is mounted from individual high-quality flexible stainless steel plates covered with special coating. The plates serve as mirrors and concentrate the reflected light at the pot with food installed at the focal point of the dish.

3.10 Solar Distillation Systems

Only 500 million people of 2.4 billion people from developing countries have access to fresh water. Solar distillation is one of alternative ways to meet needs in fresh water.

The principle of solar distillation (desalination) was known from times immemorial. As early as the 4th century BC Aristotle proposed to evaporate the water taken from the sea to produce fresh water. Nevertheless, the first large-scale solar distillation station was put into operation only in 1872 at Las Salinas in Chile. That distillation station occupied the territory with area of 4700 m^2 and produced 24000l of fresh water to provide with drinking water animals in nitrate mining. Nowadays, large distillation stations are in operation in Australia, Greece, Spain, Tunis, Caribbean islands. Small-scale solar distillers are also utilized in other countries.

Single basin solar distillers (stills) are used widely. This is an airtight reservoir that contains polluted or salted water and is covered with sloped glass or plastic cover.
The scheme of solar distillation unit is brought in Fig. 3.8. The bottom of the reservoir is blackened to effectively absorb sun radiation. Sun radiation is transmitted through glass cover and evaporates the water. Water vapors are condensed at the slanted cover of the reservoir and due to slope of cover the formed bubbles flow down to water collector trough and to drain pipe.
The water through drain pipe is discharged from reservoir and is accumulated in fresh water reservoir. The efficiency of this set depends on whether it is used in cold or warm climacteric conditions. On the average 1l/day of fresh water is produced by 1 m^2 surface of solar distillatory.
The cost of solar still depends strongly on size of the set and place of production. USA-manufactured small stills with glass cover are sold at the price of 25 USD, and with plastic cover – at 18 USD. The specific cost of 1 liter of fresh water is 10 US cents when exploitation of solar distiller is during one year.

The fresh water produced through this technology is of high-quality, and even higher quality as compared to fresh water bottled and sold at shops. All bacteria are killed in the solar still, and the content of pesticides, fertilizers and solvents is reduced by 75–99.5% [1].

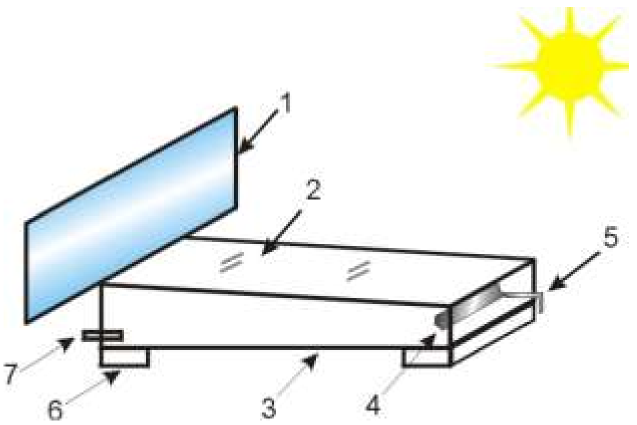


Fig. 3.8. Solar distillation unit:
1 – reflective surface, 2 – glass cover, 3 – collector with black bottom, 4 – fresh water trough, 5 – fresh water drain pipe, 6 - support, 7 – inlet pipe for polluted water

3.11 Solar Air Conditioning and Refrigerating Systems (SACRS)

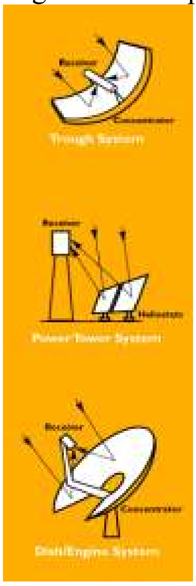
As we already mentioned this area is considered as one of most promising areas if reduced cost of equipment will be reached. In 2007, nearly 250-300 solar air conditioning systems were used in the world, 200 of them - in Europe, with that major part of them - in Germany and Spain.

The specific cost of these systems is 1300-7000 Euros per kilowatt of cooling capacity. The shares of separate components in total cost of SACRS are as follows: solar collectors - 35% is at the average, cooling components -20%, regulator and control units - 19%, other components - 26%. Four types of cooling technologies are used: absorption, adsorption, DEC solid and DEC liquid (DEC is abbreviation for desiccant evaporative cooling). In Europe, absorption systems are used in the most of Solar Air Conditioning and Refrigerating Systems. For this type of technologies specific cost is within 2600-6000 Euro/kW_{cool}. The cost is affected greatly by size and location of SACRS. For example, SACRS with absorption technology installed in Spain costs 3500 Euro/kW_{cool}, but similar system in Germany costs 5000 Euro/kW_{cool}.

The cheapest technologies are DEC with solid sorption media which can be purchased at the price from 1300 Euro/kW_{cool} to 5600 Euro/kW_{cool}. Currently, 35 SACRS are installed in Germany, 31 – in Spain, 8 in France, 4 – in Greece, 3 in Portugal, 3 in Austria, 2 – in The Netherlands, 2 – in Israel, 1 in Kosovo, Turkey and Armenia [41].

CHAPTER 4 SOLAR THERMAL POWER PLANTS

Solar thermal power technologies, that use different types of concentrators (Fig. 17), are at different stages of development.



4.1 Solar Thermal Power Plants with Parabolic Trough Concentrators (Fig. 4.1a)

Parabolic trough mirrors are used in these systems to concentrate sunlight on high-absorbance pipes filled with heat transfer fluid. The fluid is heated up to 400^0C. Overheated steam is produced through heat exchanger then that operates conventional turbine-generator system. To reduce thermal losses metal pipes with fluid are covered with transparent glass pipes. The systems are usually supplied with single-axis or double-axis solar trackers. In the mid of 80-th of last century, «Luz International» company installed 9 parabolic trough power plants with total capacity of 354MW in Southern California

◄ Fig. 4.1. The schemes of operation of solar thermal power technologies

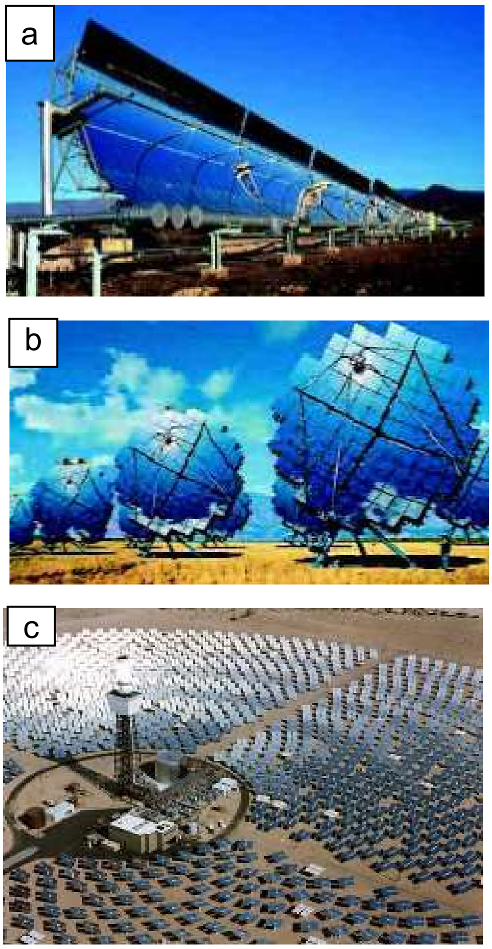


Fig. 4.2. Solar thermal parabolic trough power plant (a), parabolic dish power plant (b) and solar tower power plant (c)

4.2 Solar Thermal Power Plants with Parabolic Dish Concentrators (Fig. 4.1b)

In these power plants parabolic dish mirrors are used to concentrate sunlight on the receiver located in the focal point of the dish. The working fluid in the receiver is heated up to 1000°C and is directly used in mounted at the receiver engine that works on Sterling or Brighton cycle to produce electricity. The prototypes with capacity of 7-25 kW are installed at the different sites in USA. The maximum efficiency of these types of plants is reported as 31.25%.

4.3 Solar Tower Power Plants (Fig. 4.1c)

In these systems sunlight is focused at the central receiver installed in the upper part of the tower with the help of heliostats installed concentrically on the sun tracker. The absorbed energy is used to run turbine-generator system. The temperature of the fluid inside receiver reaches 540 -1500°C:

In 1996, “Solar Two” 10MW Solar Tower Thermal Power Plant was put into operation in the Mojave Desert, California. Technology of molten salt at temperature of 550°C as an energy storage medium was applied that allows operation of the plant all day long. Totally 1926 heliostats are used to concentrate solar radiation at the central receiver. “Solar Two” had operated till 1999. It is planned to construct similar plants with capacities within 30-200MW.

Fig.4.3 Sierra SunTower plant (5 MW)

4.4 Current Status of Solar Concentrating Thermal Power Plants

The Sierra Sun Tower facility is based on power tower CSP technology. An array of heliostats reflects solar radiation to a tower-mounted thermal receiver. The concentrated solar energy boils water in the receiver to produce steam. The steam is piped to a steam turbine generator which converts the energy to electricity. The steam out of the turbine is condensed and pressurized back into the receiver. 5 MW Sierra Sun Tower plant was put into operation in the summer of 2009. It is the only commercial CSP tower facility in North America as of spring 2010.

Sierra Sun Tower includes two eSolar modules. 24,000 heliostats, divided between four sub-fields, track the sun and focus its energy onto two tower-mounted receivers. The focused heat converts feed water piped to the receivers into superheated steam that drives a reconditioned 1947 GE turbine generator to produce electricity. The steam passes through a steam condenser, reverts back to water through cooling, and the process repeats.

Fig. 4.3. The Solar Tower Power Plant PS10

Fig. 4.4. Solar Tower Power Plants PS10 with capacity of 11MW (in the left) and PS20 with capacity of 20MW (in the right).

In the Solar Tower PS10 (Spain) with capacity of 11MW sunlight is concentrated from a field of heliostats onto a central tower. The Solar Tower PS10 is currently in operation.

PS20 solar power tower is a solar thermal energy plant in Sanlucar la Mayor near Seville, in Andalusia, Spain. It is the world's most powerful solar power tower. The 20 megawatt solar power tower produces electricity with large movable mirrors called heliostats. Construction of PS20 was started in 2006, and in 2009 PS20 was put into operation. It features a number of significant technological improvements over the earlier PS10. These include a higher-efficiency receiver, various improvements in the control and operational systems, and a better thermal energy storage system.

The solar thermal power industry is growing rapidly with 1.2 GW under construction as of April 2009 and another 13.9 GW announced globally through 2014. In Spain 22 solar thermal power development projects with capacity of 1,037 MW are under construction, all of which are projected to come online by the end of 2010. In the United States, 5,600 MW of solar thermal power projects have been announced.

4.5 Solar Ponds

In solar pond with salty water the concentration of dissolved salt in the water changes with the depth of the pond, with the highest concentration near the bottom of the pond (see Fig. 19). Bottom layer (1) is followed by layer with intermediate concentration of salt (2) where no convection is taken place, and, finally, upper surface layer (3) where thermal transfer is available. Bottom water layer is warmed by sunlight, but due to its high density it cannot move to the surface. The temperature in this layer can increase up to boiling point. The upper water layer has relatively low temperature. The intermediate layer that has salt concentration gradient serves as insulator and prevents thermal convection losses from bottom layer. The difference in temperatures between bottom and surface layers is used in different ways. It can be used also at night period.

By installing pipelines at the bottom of pond and pumping fluid through pipelines (4) it is possible to extract the heat from the bottom layer of pond and transfer it to end consumer, as well as to run turbine in closed-loop Rankine cycle to generate electrical energy.

Several power plants whose operation is based on that principle have been put into operation in Israel. The largest of them with capacity of 5MW uses waters from 2 ponds with total area of 24Ha. The efficiency of the station is 1%.

The largest solar pond in USA was put into service at El Paso, TX in 1986. It occupies the territory of 0,34 ha and provides heat to nearly located food canning plant and to 70kW power plant with Rankine cycle turbine that uses organic working fluid. The temperature of the bottom layer is 90 ^{O}C. At the same water distillation station with productivity of 20 000l/day of fresh water has been put in operation there.

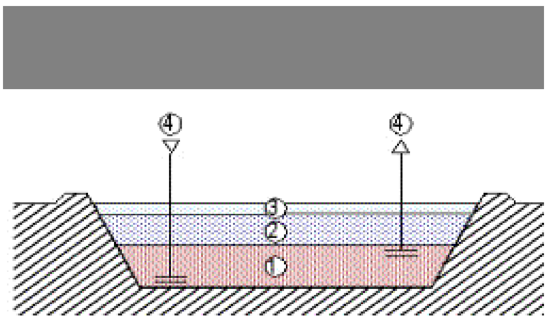
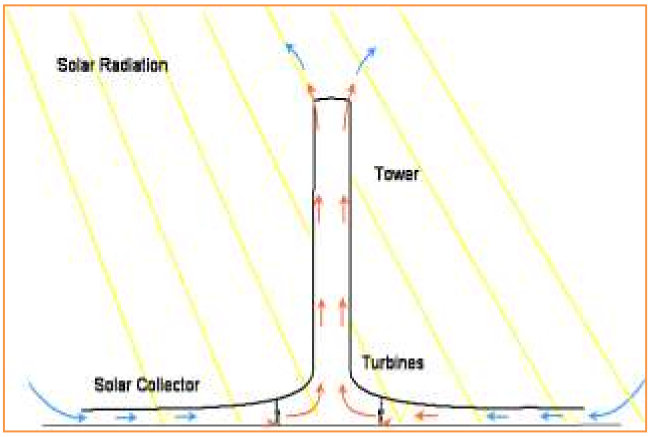


Fig. 4.5. Solar pond: 1 – water layer with high concentration of salt, 2 - water layer with intermediate concentration of salt, 3 - water layer with low concentration of salt, 4 – input of cold water and discharge of warm water.

Fig. 4.6. Solar pond at El Paso (USA)

4.6 Solar Chimney (Solar Tower)

(a)



(b)

Fig. 4.7. Solar chimney in Manzanares Spain: a) Common view, b) The scheme of operation of Solar chimney

The three main elements of solar chimney (solar tower) are solar air collector, chimney/tower, and wind turbines. Their combination to generate electricity has been described by Gunther in 1931.

The scheme of operation of solar chimney is presented in Fig. 4.7b. Air is heated by solar radiation under low circular translucent roof open at the periphery. The roof with natural ground below it forms an air collector. In the middle of the roof is a vertical tower with large air inlets at its base. The joint between the roof and the tower base is airtight. As hot air is lighter than cold air it rises up the tower. Suction from the tower then draws in more hot air from the collector, and cold air comes in from the outer perimeter. Solar radiation causes a constant updraft in the tower. The energy contained in the updraft is converted into mechanical energy by pressure-staged turbines at the base of the tower, and into electrical energy by conventional generators.

Solar Tower technology has been tested and proven with a successful small-scale pilot plant constructed in Manzanares, Spain (see 4.7a).

The plant operated for seven years between 1982 and 1989, and generated 50kW output of green energy. Its tower was 195-meters-tall and was surrounded by a transparent canopy that covered an area of about 244 meters in diameter.

The pilot plant conclusively proved the concept works and provided data for design modifications to achieve greater commercial and economic benefits associated with an increased scale of economy. Inexpensive materials were purposefully used to minimize costs, but eventually a storm blew the tower over in 1989.

Since 2001 EnviroMission has proposed to build a solar updraft tower power generating station known as Solar Tower Buronga at a location near Buronga, New South Wales. Concrete tower should be 800-1,000m tower surrounded by a greenhouse canopy 2.5 kilometers in radius on the ground. On a sunny day 32 turbines will generate up to 200 MW of electricity.

The efficiency of this solar tower is less than one tenth of efficiency of solar cells. A 200MW solar tower would cost a billion dollars to build. According to a 2005 industry report, this would imply about 10 cents per kWh, which is roughly a third of the cost of electricity from current solar cells. To be effective solar tower must be enough big.

CHAPTER 5 PHOTOVOLTAIC SYSTEMS

In 1954, Bell Company Inc. scientists Gordon Pearson, Darryl Chapin, and Cal Fuller produced a silicon solar cell with efficiency of 4%. In solar photovoltaic cells (PV-cells) the sunlight is partly converted directly into electrical current through photovoltaic effect. The generated current depends on the intensity of solar radiation and quality and type of solar cell.

5.1 Solar PV Cells and PV Modules

Most solar cells consist of a semiconductor p-n junction or Schottky barrier in which electron-hole pairs generated by absorbed radiation are separated by the internal electric field in the junction to generate a current, a voltage, or both, at the device terminals (see 5.1).

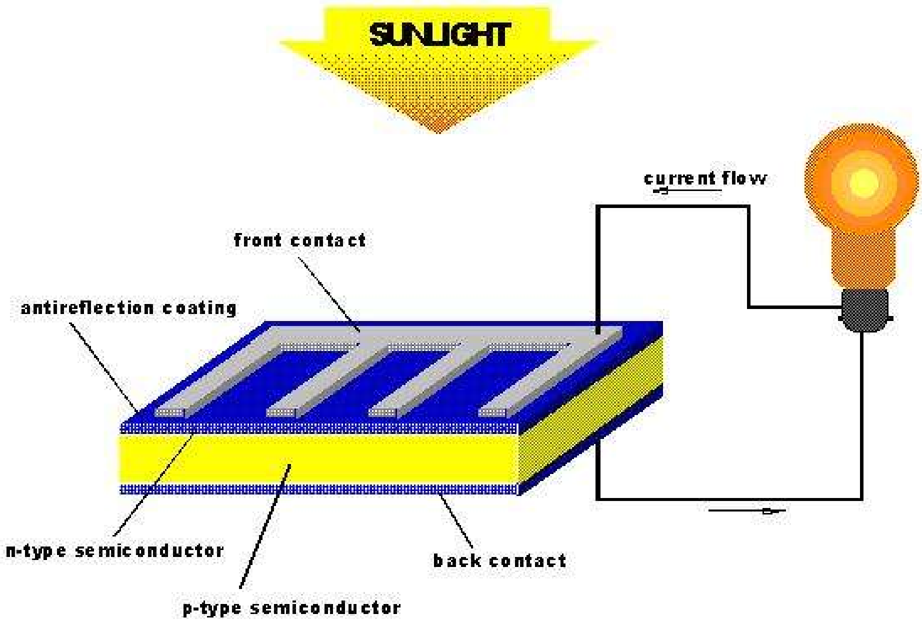


Fig. 5.1. The structure of PV-cell: 1 – anti-reflection coating, 2 – front electrode, 3 - n-type silicon, 4 - p-type silicon, 5 – back electrode, 6 - current, 7 - sunlight

Under standard test conditions (STC) i.e. when irradiance is 1kW/m^2 (AM1.5), the temperature of PV-cell is 25^{0}C, and no wind, in crystalline silicon solar cells (c-Si) open circuit voltage V_{oc} is close to 0.5-0.7V, and short circuit current I_{sc} – from tens of mA to 1-2A, with that the upper value of current is reached in high quality round solar silicon cells with diameter of 10-15cm or square solar crystalline silicon cells with side dimension of 10-15cm (Fig. 5.2). Under mentioned conditions optimal output power for different cells is within from tens of mW to 1-1.5W.

Fig. 5.2. Solar cell

PV panels/modules are fabricated from individual PV-cells. To produce the required voltage and current the PV-cells are connected to each other in parallel and in serious. The panels are insulated from outer environment, for example through lamination, and by this reducing the adverse influence of moisture on PV-cells. The capacity of individual panels is 20-150W (Fig. 5.3).

Solar PV-system of any required capacity can be easily mounted from panels. Alternating current is produced through application of inverter.

During the night or under conditions of low solar radiation back-up electrical battery is used. Control equipment provides uninterrupted operation of the all interconnected elements of the system.

5.2 Efficiencies of Advanced PV cells and Modules

The efficiencies of commercial silicon-based PV-cells and PV-modules are as follows:

- Monocrystalline silicon PV-cells (c-Si): 16-22.5%, the efficiency of modules mounted from them – 19% maximum (under laboratory conditions the efficiency of PV-cell reached 25% (UNSW PERL)),
- Polycrystalline silicon PV-cells (poly-Si): 14-17%, the efficiency of modules mounted from them – 15.6% maximum (data for 2009),
- Thin-film amorphous silicon PV-cells (α-Si): 8-9%.

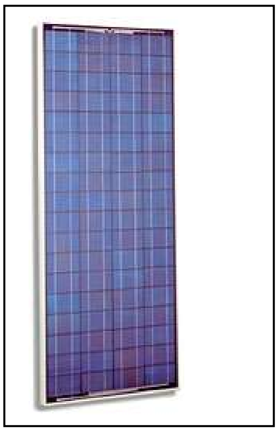


Fig. 5.3. Solar PV module/panel

Thin-film amorphous silicon PV-cells are cheaper since they contain less silicon, but they have lower efficiency and durability compared with monocrystalline silicon and polycrystalline silicon PV-cells.

Besides crystalline silicon, the following materials and their compounds are also used for PV cells fabrication: Gallium arsenide multijunction (GaAs), cadmium telluride (CdTe), copper indium diselenide (CIS), copper indium gallium diselenide (CIGS), etc.

Under laboratory conditions, the efficiency of 19.2% was reached for CIS thin-film PV-cells, and efficiency for the best commercial PV-cells of this type is higher than 11%. Maximum efficiency of CdTe thin-film solar cells under laboratory conditions was registered as 16.5% (NREL), and maximum efficiency of commercial modules – 10.4% («First Solar» company).

From point of high-efficiency of solar cells great perspectives have tandem (cascade) solar cells in which different materials are combined in a way to convert sunlight into electricity to maximum extent. There are two approaches in designing tandem structures: (1) individual cells are grown separately and then mechanically stacked one above the other and (2) each cell is grown monolithically with a tunnel-junction interconnect. So, theoretical efficiency of the tandem combination of GaInP2 (Eg=1.9eV) and GaAs is 36%. An efficiency of 40.8% under concentrated sunlight was reported for an inverted, monolithic GaInP/GaAs/GaInAs cell fabricated by and measured at the NREL in 2008.

5.3 Types of PV Stations

PV systems are usually classified into the following groups:

- Stand-alone (off-grid) PV systems (Fig. 5.4).
- Hybrid systems that are combination of PV panels and additional source of electrical energy (wind power stations, diesel or something else)
- Grid–connected PV-systems that transfer excess power to grid or receive electricity from the grid, for example, outside daylight hours.

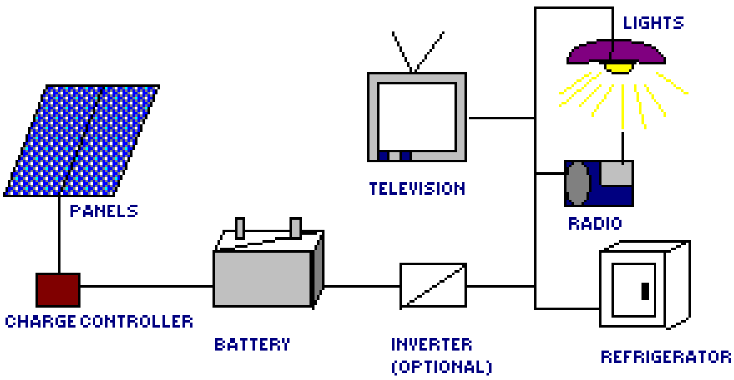


Fig. 5.4. Stand-alone (off-grid) PV system

Typical scheme of Stand-alone (off-grid) PV systems is brought in Fig. 5.4. It includes solar panels/modules, inverter to convert direct current into alternating current, charge controller to maintain operation regime of electrical battery charge and typical home appliances.

5.4 Production Costs and Prices

In Central Europe each kW of installed capacity provides 1150kWh/year of electrical energy in case of typical grid-connected PV station, and 300kWh/year of electrical energy in case of stand-alone (off-grid) PV system.

Nowadays, the cost of PV cell is around $2/W, the cost of PV module is 4-5 $/W or 3.2-4 Euro/W, and cost of energy produced is 0.25-1 Euro/kWh. It is forecasted that these costs shall continuously drop and that will cause utilization of PV-systems at larger scales in near future.

Concentrated Photovoltaic (CPV) systems make it cost-effective to generate utility-scale solar energy.

Fig. 5.5. Concentrating PV power plant in Nevada, USA. Aarrays are manufactured by Amonix (USA)

Amonix corporation located in Torrance, California (USA) applies inexpensive optics to drastically reduce the amount of expensive semiconductor material needed to produce each watt of electricity. In the Amonix system, plastic Fresnel lenses collect sunlight and concentrate it to 500 times its usual intensity onto very small, highly-efficient III-V multijunction solar cells. Concentrating PV plant in Nevada (USA) with arrays manufactured by Amonix is presented in Fig. 5.5. The company's current unit (Amonix 7700) is a massive 72-kilowatt DC (53 kW AC) system.

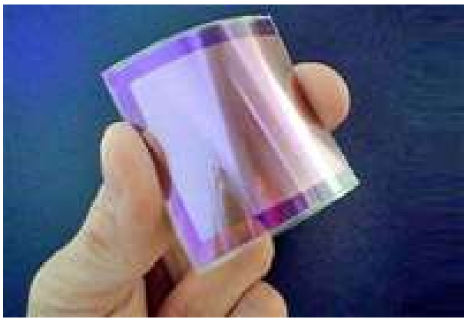


Fig. 5.6. Thin film PV cells manufactured by Nanosolar company

Based in San Jose, CA, Nanosolar corporation has developed and commercialized a low-cost printable solar cell manufacturing process. The company started selling panels mid-December 2007, and plans to sell them at around $1/W (when first announced that was just one fifth the price of the silicon cells, but in 2010 brand name silicon cells sell from around $1.70 reducing Nanosolar's cost advantage significantly).

Nanosolar company uses copper indium gallium diselenide (CIGS)—which achieves up to 19.9% efficiency in laboratory samples to build their thin film solar cells. Nanosolar's solar cells have been verified by NREL to be as efficient as 14.6% in 2006 and 15.3% in 2009. Nanosolar claims to be able to produce electricity at 5-6 cents/kilowatt hour almost as cheap as power from coal and at about one-third the cost of other solar power.

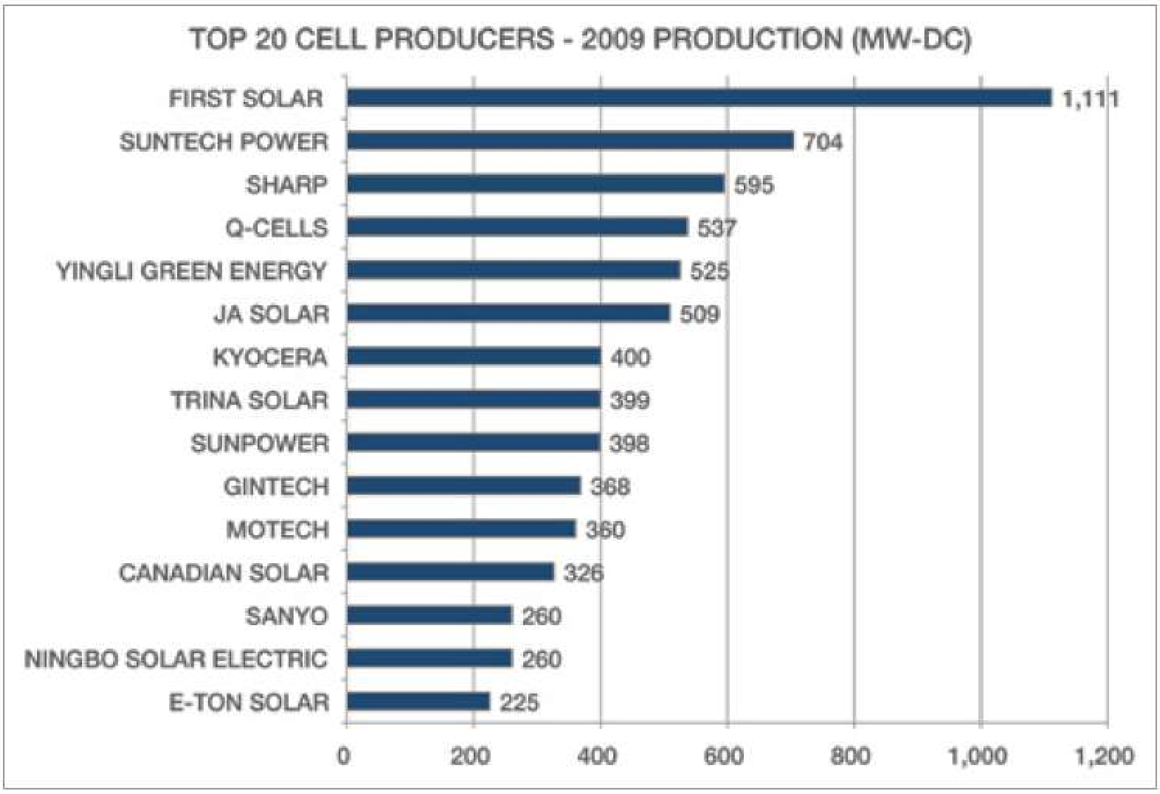


Fig. 5.7. Top 20 PV Cell producers - 2009 production (MW-DC) [44]

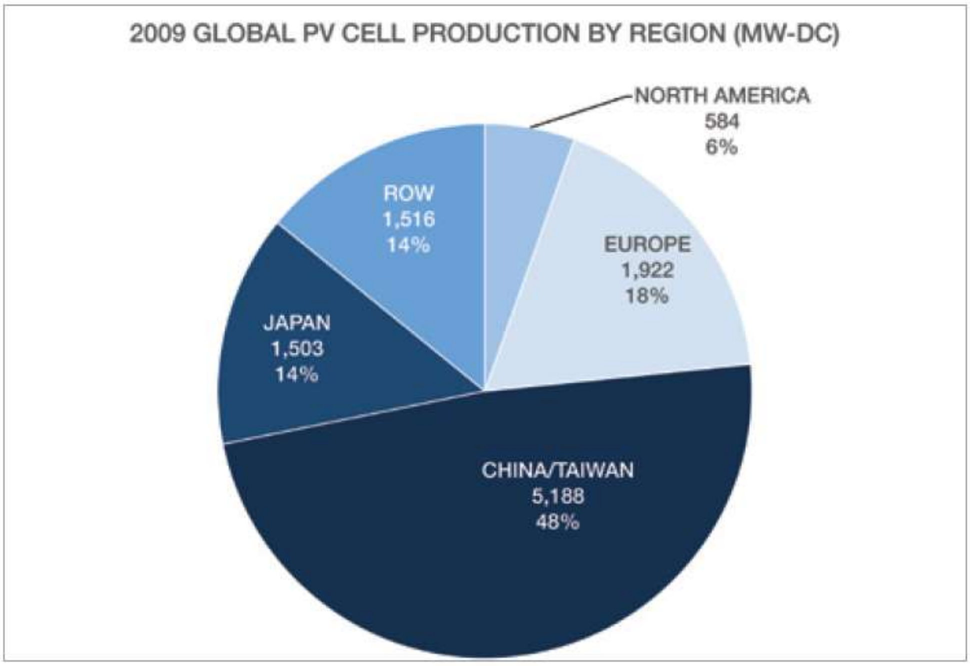


Fig. 5.8. 2009 Global PV Cell Production by Region (MW-DC) [44]

5.5 Solar PV Power Plants in Operation

Fig. 5.9. Use of PV system at gas-filling station.

Fig. 5.10. Modern PV cell production line in Taiwan [22]

«Acciona Energy» company from Spain lately has put into service in South-Western part of Portugal the largest in the world PV plant with capacity of 46MW (see Fig. 5.11a) as of 2008 [23]. Total area of PV plant is 250 Ha, and is composed of 2520 solar tracking systems at which 262000 polycrystalline silicon modules are installed each with capacity of 170-180W. Annual average electricity production is 93 million kWh. The total investments by «Acciona Energy» company were 261 million Euros.

Fig. 5.11a. The PV-plant in Europe [40] with capacity of 46MW (2008)

Fig. 5.11b. The largest in the world Sarnia PV Plant with capacity of 80MW installed in Canada (2009-2010). Picture courtesy First Solar

Located in Canada, Sarnia PV Power Plant with capacity of 80 MW (see Fig. 5.11b) was constructed in 2009-2010. It is the largest PV Plant in the world as of 2010.

5.6 Impact on Environment.

Operation of solar PV-system has not adverse influence on the environment. Some risks with adverse influence on the environment are associated with PV cells production technologies, as well as with production of electrical batteries and storage of utilized electrical batteries.

CHAPTER 6 SOLAR ENERGY USE IN ARMENIA

6.1 Estimation of Resources

Natural climatic conditions in Armenia are enough favorable for solar energy use. Annual average value of sunshine hours is 2500 hours. Average annual flow of solar radiation on horizontal surface is 1720 kWh/m^2. For comparing purposes, in Central Europe this average value is 1000kWh/m^2, particularly, in Poland, Czech Republic, and Slovakia 950-1050kWh/m^2, in Hungary - 12000kWh/m^2, in Bulgaria - 2000kWh/m^2 [24].

Data on solar direct (beam) radiation are received through actinometrical measurements. The actinometers (pyrheliometers) are installed only at six monitoring stations in Armenia (Armhydromet data) [32]: Yerevan-agro (elevation is 942m above sea level), Gyumri (1500 m), Tashir (1300 m), Sevan (1918m), Martuni (1940m), Kochbek (2400m): A large part of actinometrical and sunshine duration data for territory of Armenia were processed and analyzed before 1980. The regime of solar radiation under conditions of mountainous relief was investigated relatively weak [31].

On the territory of Armenia, actual annual average hours of sunshine (i.e. possible sunshine hours minus time period during which the sun is covered by clouds) depends on site of consideration and varies from 2000 to 2800hours/year [31] .This value constitutes more than 50% of possible sunshine hours. Actual sunshine hours for Yerevan are 2700, for Martuni - 2750, for Ashtarak - 2837, for Vanadzor - 2019, for Idjevan - 1827 hours. For the territory of Armenia as a whole, actual annual average hours of sunshine are equal to 2500 hours [26]:

Under different conditions on the territory of Armenia, annual average incident solar total irradiation (i.e. irradiation integrated within year per unit of horizontal surface) is from 140kcal to 155kcal/cm^2. There exist some discrepancies in data received from different authors.

Distribution curve of the density of annual energy flow of total solar irradiation per 1m^2 of horizontal surface is brought in the Fig. 6.1 [26]. As can be seen from the Fig. 6.1, for at least of one quarter of the territory of Armenia annual average solar total irradiation is 1850 kWh/m^2

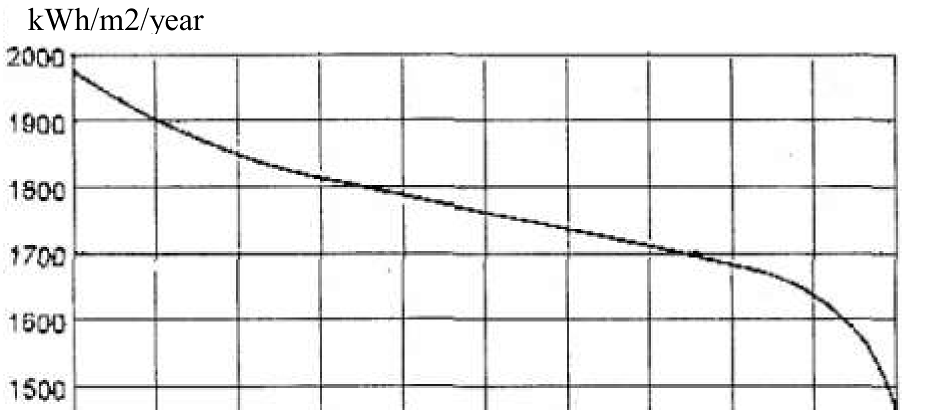


Fig. 6.1. Distribution curve of the density of annual energy flow of total solar irradiation per 1m^2 of horizontal surface

11-15% of annual average solar irradiation falls on winter months [31]. These values grow as the elevation of the site increases. 60-65% of energy of total radiation is the energy of beam (direct) radiation.

Data on mean daily total (E_{tot}) and diffused (E_{dif}) irradiation (MJ/m^2) and ambient temperature T_{amb} (^0C) averaged for month as per months are brought for Yerevan in Table 2 below. The maximum values for incident solar total radiation are received for 6^{th}-7^{th} months, and the maximum values for solar diffused radiation – for 5^{th}-6^{th} months of the year (see Fig. 6.2). Average annual value of solar irradiation per unit of horizontal surface is 203.18MJ/m^2 (1693.2 kWh/m^2). Let's note that Yerevan-agro is at 10km from Yerevan, at open site in v. Parakar.

Table 2. Data on mean daily total (E_{tot}) and diffused (E_{dif}) irradiation (MJ/m^2) and ambient temperature T_{amb} (^0C) averaged for month as per months on 1 m^2 of horizontal surface, Yerevan, 40.1^0 N.Lat. [24]

Month / Parameter	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Etot	6.34	10.13	14.04	19.18	24.97	28.22	27	25.11	20.15	14.85	8.06	5.13
Edif	4.05	5.96	7.02	8.2	8.23	7.78	6.88	6.34	5.38	4.86	3.89	3.1
T_{amb}	-3.7	-2.3	4	11.1	15.9	20.1	24	24.2	20	13.9	6.2	-1.2

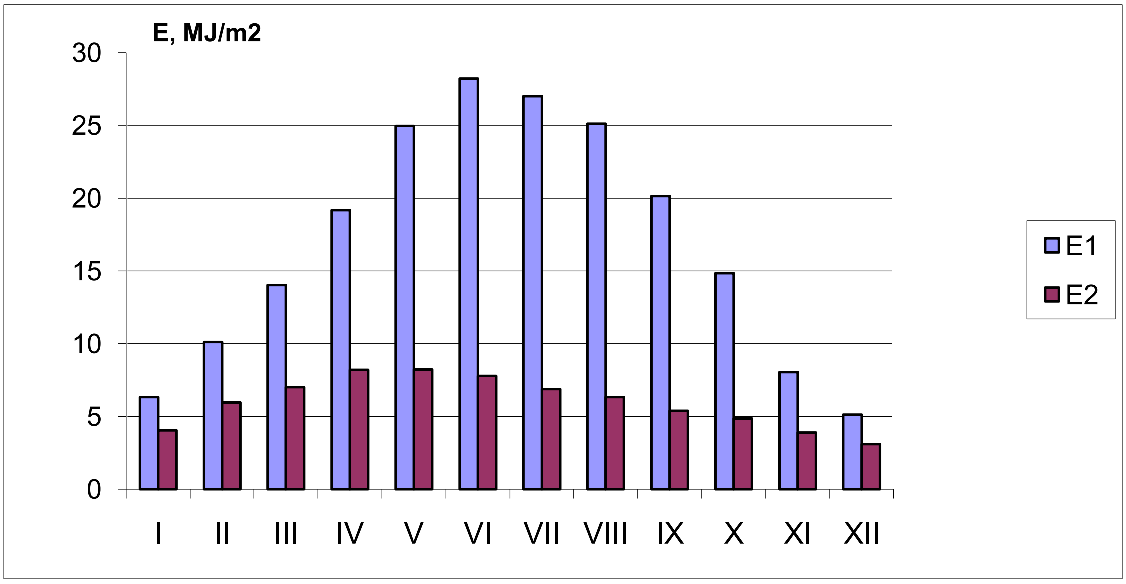


Fig. 6.2. Data on mean daily total (E_1) and diffused (E_2) irradiation (MJ/m^2) averaged for month as per months on 1 m^2 of horizontal surface, Yerevan, 40.1^0 N.Lat. [24]

Currently, several organizations, particularly Solar LLC and American University of Armenia (AUA) are also provided with appropriate equipment to measure incident beam (direct) and total solar radiation.

Definitions:
Irradiance [W/m^2]. The rate at which radiant energy is incident on a surface, per unit area of surface. The symbol G is used for solar irradiance, with appropriate subscripts for beam, diffuse, or spectral radiation.
Irradiation [J/m^2]. The incident energy per unit area on a surface, found by integration of irradiance over specified time, usually an hour or a day. Insolation is a term applying specifically to solar energy irradiation.

6.2 Description of Implemented Projects

In 1981, pilot two-storey apartment building with active solar system of heat supply based on solar collectors was constructed in v. Merdzavan. Designing works were implemented by the Institute of High Temperatures of Academy of Sciences (IHTAS), Russia and HayGiprogyughtntesutyun (currently ArmAgricultureConstructionDesign LLC), Armenia. The solar system included solar flat-plate water heaters with total surface of 32 m^2, heat storage system, as well as control and monitoring equipment. The solar system covered 55% of annual heat consumption needs of two-storey apartment building and saved up to 3 tons of coal equivalent. The designed cost of solar system (5500 rubles in SU prices) was 15.5% of the total cost of the apartment building. Currently, the solar system is dismantled.

Fig. 6.3. Solar station Arev-120

Pilot project of solar thermal power station Arev-120 was not completely constructed (see Fig. 6.3). The site of the plant – Aragats scientific polygon of Scientific and Research Institute of Radiophysics The project has been developed by team managed by academician P.M. Geruni. The design power was 120 kW. Several patents were issued since 1992. There is one fixed spherical mirror (part of sphere). Air is heated in thermal exchanger and conveyed to turbine. The last is rotated and put into rotation electrical generator and compressor. There were plans to increase output power up to 1 MW. The future of this station is unclear.

Below are brought description of the solar energy utilization projects: first, short description of projects implemented in 1992-2003 (see also [14]), then description of the projects implemented in the last years.

Fig. 6.4. 7.5 kW PV station in t. Gyumri

In 1992, BP company (UK) installed solar photovoltaic station with installed capacity of 7.5 kW in the school named after Byron in t. Gyumri (Fig. 6.4).

In 1994-1996 “Contact-A” LLC has manufactured and installed 108 solar modules (each with capacity of 30W) on 35 seismic observation stations throughout Armenia, around Metsamor Nuclear Power Plant and Spitak Earthquake zone. The project was funded by FAR

The Laboratory of Heliotechiques of Center of Small Power Systems of the State Engineering University of Armenia within several years implemented several projects presented below.

- In 1995, solar photovoltaic panels with total capacity of 2.4 kW were installed on the roof of St. Sargis Church in Yerevan.
- In 1995, solar photovoltaic panels with total capacity of 2.4 kW were installed on the roof of Musical recording center of Armen-Hakob Culture Center in Yerevan.
- In 1997, solar photovoltaic panels with capacity of 320 W were installed on the roof of block N 17 of administrative building of SEUA to back up electricity supply of the computer center.

In 2000-2001, 15 pilot solar water heaters were installed for free on the territory of Armenia during the implementation of two-year program ARMNEDSUN sponsored by the Government of the Netherlands. Joint venture SunEnergy LLC was established between ZEN (The Kingdom of the Netherlands*)* and Technokom LLC (Armenia) that started manufacture of solar water heaters in Armenia. At present, less than two thousands m^2 of solar water heaters were installed by SunEnergy JV and Technokom LLC on the territory of Armenia, particularly on the roofs of seven homes in "Vahagni" residential community (Fig. 6.5), in Terdjyan Hotel ($22m^2$), in v. Tsapatagh near Lake Sevan, on the roof of building at Northern avenue (400 m^2).

Fig. 6.5. Solar collectors installed in v. Vahagni, near Yerevan

Fig. 6.6 The combined solar and water heating system at Northern ave. 10 (Yerevan)

Solar water-heating system combined with boiler house (Fig. 6.6) was put into operation in October 2007 by LLC Technokom at the address: Northern ave. 10, Yerevan, Armenia. The power of boiler-house operated on natural gas is 3 200 kW. The area of solar collectors is 400 м^2. The total volume of storage reservoirs is 16 000 liters. Three-cascade collector block and two-step heat transfer system was used.

In 2002, Solar driven desiccant cooling demonstration system (Fig. 6.7) was installed and put into operation in American University of Armenia (AUA) with funding from European Commission. The system of solar water heaters (Fig. 6.7) with capacity of 40kW and total surface of 64m^2 was installed on the roof of AUA.

In 2003, solar photovoltaic station with rated capacity of 5 kW (see Fig. 6.7) was installed and put into operation which included 72 photovoltaic panels with total surface of around 50m^2. DC/AC inverter of 10 kW was manufactured in Armenia and installed in AUA for this system.

Fig. 6.7. Solar photovoltaic station and solar water heaters installed on the roof of AUA

In 2006, “Viasphere techno park” CJSC (Armenia) designed, installed and put into operation solar photovoltaic station with installed capacity of 5 kW (Fig. 6.8). To receive the maximum value of power during the day one-axis solar tracking mechanical system was developed. Single crystalline solar cells of high quality manufactured in Russia with efficiency of 18% were used for modules. Totally 30 photovoltaic modules were made by “Viasphere techno park” CJSC. Three-phase DC/AC inverter (from direct current to three-phase alternating voltage of 380V) of 5 kW capacity was manufactured in “Viasphere techno park” CJSC and used in the system. This voltage was applied to water electrical pump that pumped water from depth of 30m up into water reservoir for subsequent utilization.

Fig. 6.8.

5kW Solar photovoltaic station with solar tracking system (picture courtesy Viasphere techno park)

Within the frame of the program “Development of Up-to-date Solar Photovoltaic Industry in Armenia” under contract with R2E2 Foundation [9], the consortium of DEM (Denmark) and Solaren LLC (Armenia) in 2008 proposed to organize production of solar photovoltaic panels based on poly crystalline cells and poly-crystalline mixture manufactured through Siemens technology processes. It was suggested also to construct 3kW demonstrational photovoltaic station with concentrators based on Amonix (USA) technology. Besides, it was suggested to conduct additional research work regarding introduction of technology of production of metallurgical silicon of high purity in Armenia.

One of leading organizations in Armenia involved in introduction of renewable energy resources SolarEn LLC have installed solar photovoltaic stations and systems with total capacity of 20 kW and solar water heaters with total surface of collectors of 600m^2 in different areas of Armenia.

Descriptions of implemented projects on solar energy utilization in the last years are brought below.

Fig. 6.9. 10 kW solar photovoltaic station installed at Armenian-American Health Center

In 2007, 10kW solar photovoltaic station, building integrated, connected to electrical network was installed at Armenian-American Health Center by SolarEn LLC for the first time in CIS-countries (Fig. 6.9).

144 solar panels were installed. Each panel is an amorphous silicon cell laminated on stainless steel plate with thickness of 0.7мм and dimensions of 330cm•45cm. The rated capacity of panel is 68W. The system is connected to 3-phase electrical network through 3-phase inverter [17].

a b

Fig. 6.10. Solar water heaters: a. Solar water heaters at the roof of Red Cross Rehabilitation Center (Yerevan); b. Solar water heaters at Narcologic Clinic integrated with back up gas boiler (Yerevan)

Solar water heating system with total surface of solar collectors of 150m² for space heating and hot water supply was installed at Red Cross Rehabilitation Center in Yerevan. The system was integrated with boiler house of the Center operated for heat and hot water supply (Fig. 6.10a) [17]. Another solar water heating system with total surface of solar collectors of 140m² (Fig. 6.10b) was installed at Addiction (Narcological) Clinic integrated with back up gas boiler (Yerevan) [17]. These two above-mentioned programs were implemented within Hellenic Aid Programme during 2007-2008. Total surface of solar collector at both was 290m², and total capacity of 140 solar water heaters was 210 kW.

Fig. 6.11. Solar water heating system integrated with boiler house. Total area of collectors is 70 m² (2008)

Fig. 6.12. Solar water heating system. Total area of solar collectors is 13m2 (2006)

Fig. 6.13. Solar water heating system installed in the yard of Vasgenian theological seminary (Sevan) [18]

54kW solar water heating system (Fig. 6.11) with total area of solar collectors as much as 70m² was installed at boiler house (Yerevan, Avetisyan 23) to provide heat to multi-apartment buildings. (2008). This project was implemented with co-funding from UNDP and ErFrez company [17].

9kW solar water heating system that includes 6 solar water heaters with total area of 13m2 was installed at private house in Nork-Marash (Fig. 6.12). The system is integrated with local boiler system and provides hot water supply rooms, swimming pool and shower bath (commercial project).

In 2009, solar water heating system was installed and put into operation at Vasgenian theological seminary (Sevan) with co-funding from "Armenia - Improving the Energy Efficiency of Municipal Heating and Hot Water Supply" UNDP/GEF Project and World Council of Churches Round Table Armenia (WCC RTA) fund (Fig. 6.13). The aim of the project is to meet needs in hot water supply of 90 students and staff at Vasgenian theological seminary (Sevan) through introduction of solar collectors. The project was implemented by SolarEn LLC. Solar water heating system with total area of solar collectors as much as 60m^2 was installed in the yard of the seminary and connected to the existing boiler house that operated on natural gas

Fig. 6.14. Combined system of solar photovoltaic panels and wind turbines

Free Hold Power" scientific foundation with financial and technical assistance from International consortium that includes "Denali" holding Inc. (USA), "Juliette" Ltd (Great Britain) and "Renessans" SRL (Italy) companies developed mobile station that uses renewable energy resources. Pilot station with capacity of 5kW was designed and constructed (see Fig. 6.14). The station is in operation from more than year. The system is completely automated, no service staff is required to maintain operation of system, and it can be operated remotely from computer. The system can be supplied diesel generator, as well as with generator to produce clean water from atmosphere.

Basic operational data of the pilot system: installed capacity – 5kW, including total capacity of solar photovoltaic modules – 3.5kW, wind turbine capacity 1.5kW. The system allows to generate high-quality (as per frequency and voltage stability) electrical current with sine shape.

CHAPTER 7 BIOMASS

7.1 Introduction

Biomass is non-processed (raw) or processed organic material that possesses chemical energy. Nowadays by biomass we understand any material of biological origin, products of biological activities, and organic wastes generated during their processing. Biomass is produced by plants through photosynthesis reaction when absorbing solar radiation. Different thermal, chemical or biotechnological processes have been developed to produce energy or fuel from biomass. Annual growth of biomass worldwide totals 200 billion t, or expressed in energy equivalent is $3 \cdot 10^{21}$J. This is ten times as much as annual energy consumption in the world.

Biomass can be used in the following ways [5]:
a) Production of thermal or electrical energy;
b) Production of different types of fuel, including:
- Solid fuel: fuel wood, wood chips, and pellets,
- Liquid fuel: bio-ethanol, biodiesel fuel (methyl esters), bio-oil,
- Gaseous fuel: biogas, hydrogen, and other gases.

Biomass that is processed in sustainable way is considered renewable energy resource. Data on energy production from biogas worldwide are brought in Table 1.

In 2001, traditional use of biomass as a fuel wood totaled 9.3% of primary energy consumption worldwide, and energy use of biomass processed with modern technologies – 1.4%.

Fig. 7.1. Wood pellets

Fig. 7.2
Fast growing plants

7.2 Solid Fuel

The largest source of biomass is wood from forestry and wood processing industry. Wood materials: bark of trees, wood chips, pellets has different characteristics (see Table 3). Currently, pellets are considered as very promising type of wood fuel.

Table 3. Characteristics of different types of fuels

Fuel	Moisture content, %	Lower heating value, kWh/kg	Ash content (% of dry matter)
Wood without bark	50-60	5.1-5.6	0.4-0.5
Bark	45-65	5.1-6.4	2-3
Forest residues (coniferous with needles)	50-60	5.1-5.6	1-3
Straw	10-25	4-4.2	3-5
Pellets	<10	<4.7	<0.7
Coal	6-10	7.2-79	8.5-10.9

In addition to traditional way of combustion of wood other technologies, including pyrolysis and gasification technologies, as well as combined combustion technology (co-firing of different types of biomass or co-firing of biomass with coal) are at different stage of development.

7.3 Liquid Biofuel

Bio-ethanol, bio-diesel fuel (methyl esters), and bio-oil are different types of liquid bio-fuel.
Bio-ethanol (ethanol, C_2H_5OH) is produced from plants containing sugar and starch` sugarcane and sugar beet, corn (maize), cereals, sweet sorgos, grapes, and other plants through hydrolysis process. In 1903, Brazil was the first country that used ethanol as motor fuel. Currently it implements the largest program in ethanol production in the world. Bio-ethanol is added to petrol with percentage of 5-25% (for example` in mixture labeled as E10 content of ethanol is 10%, petrol - 90%) to mitigate impact on environment from fuel combustion. As a result, emissions of CO, SO_2, and CO_2 are reduced.
The raw materials that are used for bio-ethanol production can be classified into three groups:
a) Plants containing sugars: sugarcane, sugar beet etc.
b) Plants containing starch: cereals and root (to become sugars applicable for fermentation they shall be processed through hydrolysis);
c) Wood materials, agriculture wastes, cellulose. The last one is transformed into sugars through process of acid or enzymic hydrolysis. In spite of recent achievements cellulose ethanol production is still in pilot. Nevertheless, in 2004, Iogen Inc. (Canada) started production cellulose ethanol at commercial basis. 25 years for research and developments and investments in the amount of 110 million Canadian dollars was required from this company and its partners.
By the end of 2008, 67 billion l of bio-ethanol was produced worldwide. Production costs of bio-ethanol from sugar are 25-30 cent/l, and from maize - 40-50 cent/l.

Bio-diesel Fuel. Rudolf Diesel demonstrated its first engine that run on peanut oil in Paris in 1900. The choice of raw materials for biodiesel production is wider compared with bio-ethanol production. It is mainly produced from oilseeds, i.e. from oil of rape, sunflower, soy and palm seeds, as well as from fats of animals and wastes of organic products.
In European Union, biodiesel fuel is mainly produced in Germany, France, and Spain. In EU 80% of biodiesel fuel is produced from rape-seed oil. In USA that is at the second place in the list of biodiesel producers, it is produced from soy seeds. A significant progress is anticipated in Brazil, where this type of fuel is still produced in small volumes. It is necessary to mention that one quarter of palm oil is used mainly for biodiesel production.

Fig. 7.3. Bio-diesel fuel production plant

7.4 Gaseous Bio-fuel: Biogas

Biogas production is an important technology for biomass utilization in Armenia. The use of biogas production plants allows solving several tasks unanimously: production of gas and electricity, processing of agricultural wastes, production of high quality fertilizers. This type of fertilizers is also used as valuable additions to animal's food. The main sources of biogas are urban solid wastes (to produce landfill gas), municipal sewage waters, manure of agriculture animals and poultry, remnants of flora and forestry entities. The biogas is produced in bioreactor (methane tank) through anaerobic digestion technology.

7.5 Technological Schemes of Operation of Equipment for Biogas Production

Biogas is produced in special hermetic vessels – bioreactors (methane tank, pressure chamber) through anaerobic digestion of agriculture animals and poultry. The process of digestion is going on through three stages with participation of two groups of bacteria. During the first stage through fermentation hydrolysis complex organic compounds (fat acids, proteins, and hydrocarbons) decompose into more simple aggregates. During the second stage simple organic aggregates are exposed to influence by facultative anaerobic (or acids forming) group of bacteria. Mainly volatile fat acids are formed through these processes. During the third stage organic acids influenced by anaerobic (or methane forming) bacteria are turned into carbon dioxide (CO_2) and methane (CH_4). According to different references, nearly 1000 microorganisms of various types are involved in these processes. Heat value of biogas produced is within 5340-6230 kcal/m^3.

Data on biogas properties are brought in Table 4, and data on output of manure and biogas against the type and the mass of animal or poultry are brought in Table 5 [15].

Table 4. Physical parameters of biogas [15]

Parameter	Component				Mixture 60%CH_4+ 40%CO_2
	CH_4	CO_2	H_2	H_2S	
Volumetric concentration, %	55-70	27-44	1	3	100
Volumetric combustion heat, MJ/m^3	35.8	-	10.8	22.8	21.5
Temperature, C^o - ignition - critical	 650-750 82.5	 - 31.0	 585 -	 - 100	 650-750 2.5
Density, - normal, g/L - critical, g/L	 0.72 102	 1.98 408	 0.09 31	 1.54 349	 1.20 320

Table 5. Data on output of manure and biogas depending on type and mass of animal or bird [15]

Parameter	Milky cow (454 kg)	Hen (2.3 kg)	Pig (45.5 kg)
Output of manure, kg/head/day	55.0	0.3	3.5
Biogas output, m^3/head/day	1.62	0.02	0.32

The technological scheme of biogas production is brought in Fig. 40. The following activities are applied for manure digestion

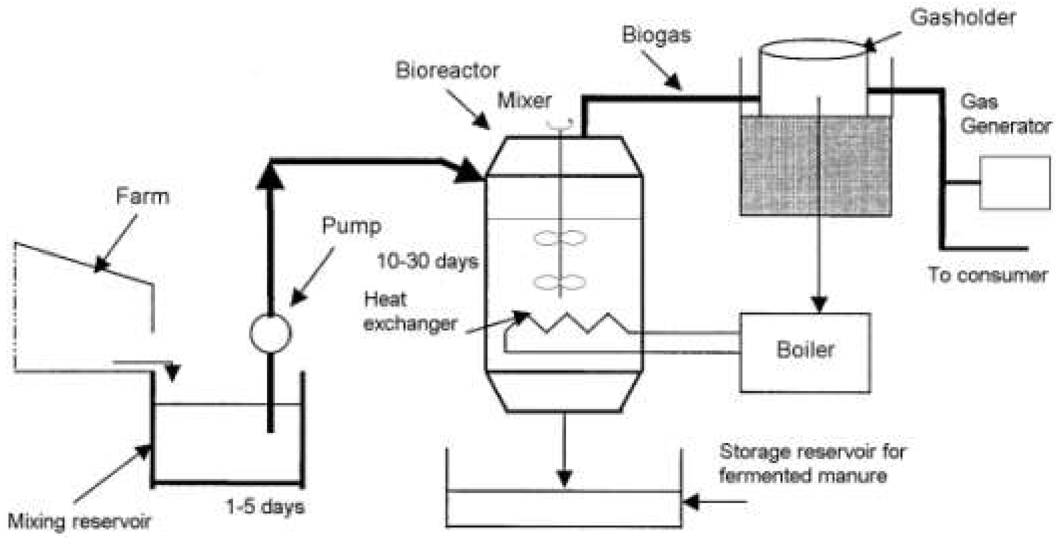


Fig. 7.4. The technological scheme of biogas production

The manure from animal farm is transported to mixture reservoir. Then it is pumped by sewage waters pump to bioreactor where anaerobic fermentation and biogas production takes place. The biogas produced is accumulated in gasholder and used by consumers as per demand.

The thermal regime in the bioreactor is maintained with help of heat exchanger through which the water warmed in boiler flows. Only part of biogas produced is used for operation of boiler. Fermented manure is transported to manure storage reservoir.

7.6 Impacts on Environment

Through operation of biogas production plant emission of GHG are reduced comparing with the storage of manure in open air. Also epidemiologic situation and sanitary conditions become improved as a result of elimination of adverse pathogenic bacteria and microorganisms in the wastes.

Operation of biogas plants requires accurate maintenance of work regimes. There exists high demand in agriculture in fermented manure and its availability will reduce dependence on traditional mineral fertilizers that are mainly are brought from abroad.

7.7 Prospects and Projects Description of Biogas Production in Armenia

According to estimates, it is possible to construct biogas production plants with total capacity 100 000 m ^{3}/day in the coming 15 years in case of involvement and availability of foreign investments. In 2006, in the frames of “Renewable Resources and Energy Saving National Program of RA” the perspectives of implementation of most technically and economically feasible projects for biogas production from manure of agriculture animals and poultry, municipal solid wastes, municipal sewage waters till 2020 were estimated [16]. The data received are brought in the Table 6 below.

Fig. 7.5. Lusakert Biogas Plant

Fig. 7.6. Gas engine installed at Lusakert Biogas Plant

In 2008, “Lusakert Biogas Plant (LBP), methane capture and combustion from poultry manure treatment” program was successfully implemented in Armenia with additional financing through Clean Development Mechanism (CDM). Due to plant’s operation annual reduction of 62832 t CO_2 is reached (see Fig. 6.5-6.6). Installed capacity and annual average electricity production of power plant are 0.85 MW and 7 million kWh correspondingly [12, 18].

Table 6. Forecasts of biogas production in Armenia in 2020

Source of biogas	Volumes of investments, Million USD	Annual volumes of biogas million m^3/year	Annual saving of organic fossil fuel, thou. tce	Payback period, years	Reduction of GHG emissions, thou. t CO_2/ year	Ration of annual fossil fuel savings to investments, thou. tce/ million USD
Manure from cattle farms	0.73	1.06	0.83	8	15.57	1.15
Manure from pig farms	0.21	0.3	0.24	8	4.41	1.15
Manure from poultry farms	16.55	9.79	7.69	8	206.84	0.46
Nubarashen municipal landfill	6.83	9.72	7.62	8	135.0	1.12
Landfills of other cities of Armenia	3.85	5.47	4.29	8	76.08	1.12
Municipal sewage waters	6.01	12	9.43	8	106.7	1.57
Total	34.17	38.34	30.10		544.6	

Technical and economic data on biogas plants in Armenia and their current status are brought in Table 7

Table 7. Technical and economic data on biogas plants in Armenia and their current status.

No	Name of station	The volume of methane tank, m^3	Biogas output, m^3/day	Capital investments, USD	Start of operation	Current status
1.	Small biogas station (manure from cattle) combined with solar collectors	6	8-10	3000	1988	In operation (under question)
2.	Experimental small biogas station at Lusakert poultry factory	50	90-135	30 000	2002	Not in operation
3.	Biogas production station at “Agroservice” Ltd (manure from cattle) v. Shahumyan	25	50	12500	2003	Not in operation
4.	Small biogas plant in v. Slovak, Gegharkunik marz	25	15	15 000	2005	Not in operation
5.	Small biogas stations in Gegharkunik and Tavush marzes (manure from cattle) (WB program)	3-4,5	6-9	1250	2005	A few are in operation (under question)
6	Biogas plant in v. Arzni combined with solar collectors	25	14-15	n/a	2006	Not in operation
7	Lusakert biogas plant at Lusakert poultry factory	4400	9600	3.4 mln.Euros	2008	In operation

7.8 Prospects of Bio-ethanol Production in Armenia

In 2008, “A Preliminary Feasibility Assessment of the Preferred Alternative For Implementing a Commercial Scale Bio-Ethanol Fuels Program For Armenia in the Near to Mid Term” report implemented in frames “Assistance to the Bio-Ethanol Production Development in Armenia” grant was submitted by Enertech International, Inc. and BBI International to the Renewable Resources and Energy Efficiency Fund of Armenia [10].

Alternative acceptable food stocks were selected to plant in the lands that were not allocated for agriculture utilization due to climatic and other conditions of Armenia.

The best feedstock being able to be grown on non-used lands in Armenia, as well as being processed in plants utilizing commercially available processing technology in the near to midterm, include Jerusalem Artichoke, Feed Corn for livestock and poultry, Sweet Sorghum, and Chicory.

In this document it is envisaged to construct one plant based on inulin extraction process for 7000 tones of Jerusalem artichoke per annum and the other plant based on a dry milling process with fractionation utilizing 7000 tones feed corn per annum.

Two versions were considered in prefeasibility study. In the first version as a raw material Jerusalem artichoke was selected. Also opportunity of inulin extraction process for Jerusalem artichoke was taken into account. Plant is planned to be located in the vicinity of Sisian and Goris in Syunik Marz. In the second version as a raw material feed corn was selected, and plant location shall be in Tavush Marz.
Total capital investments for construction of bio-ethalon plant were estimated in the amount of 17 million USD as per the first version, and 19 million USD as per second version. Retail price of bio-ethanol fuel was estimated at 1.34 USD/l.

In the mid to longer term perspectives the best feedstock for cellulosic conversion include:
- Grain straw
- Fast growing hybrid trees (such as poplar, mulberry, and willow).

CHAPTER 8 WIND ENERGY

Fig. 8.1. Wind power plants with horizontal axis of wind turbine

1-2% of incident solar energy that reaches the Earth surface is conversed to wind energy. Since ancient times wind energy has been used in windmills, to drive water pumps, in sailing etc. Oil crisis of seventies of last century has stimulated intensive researches to develop economically feasible technologies in the area of wind energy applications.

The present generation of wind turbines proved in practice their efficiency during tens of years of operation and necessity for large scale introduction: The capacities of modern industrial wind power plants (WPP) are in the range from tens W to 5MW. By the end of 2008 total installed capacity of wind power plants was equal to 121GW, i.e. around 27% raise compared with 95GW of 2007 [6].

8.1 Basic Considerations

The energy of air flow of density ρ and volume V with cross section A and length δx that moves with velocity υ can be expressed as

$$E = \frac{\rho A(\delta x)\upsilon^2}{2}$$

Correspondingly, wind power density is expressed as

$$P_w = \frac{dE}{dt} \times \frac{1}{A} = \frac{\rho}{2}\left(\frac{\delta x}{\delta t}\right)\upsilon^2 = \frac{\rho \upsilon^3}{2} \text{ [W/m}^2\text{]}$$

From (8.2) followed that wind power density increase 8 times as air flow velocity increase twice. P_w = 450 W/m^2 at the height of wind turbine is considered as a good parameter for operation of wind power plant.

It is well known that air density is expressed as

$$\rho = \frac{P}{RT},$$

where R is gas constant, P is air pressure, T is air temperature. Seasonal changes in air density can reach 10-15% depending on the pressure and temperatures changes and cause seasonal changes in electricity production at wind power plants.

Only part of air stream energy can be used by wind energy plant. The maximum value of power density that can be extracted from air flow is defined as

$$\left(\frac{16}{27}\right) \times P_w = 0.593 \times P_w$$

0.593 is referred to as the Betz limit (1919ϸ.) [20].

8.2 Wind Velocity Changes with Altitude

It is possible to accept that at altitudes less than 10m the velocity is not changed. For higher altitudes velocity change can be extrapolated for many cases by the following equation:

$$\upsilon(h_2) = \upsilon(h_1) \times \left(\frac{h_2}{h_1}\right)^{1/7}$$

where $\upsilon(h_1)$, $\upsilon(h_2)$ are the velocities of wind at the altitudes of h_1 and h_2 correspondingly. If wind speed frequency distribution probability is approximated by Rayleigh probability density function then the power density at the altitude of 50m is twice the power density at the altitude of 10m. It is necessary to note that wind speed frequency distribution is better approximated by Weibull distribution and information on it can be received from special technical literature.

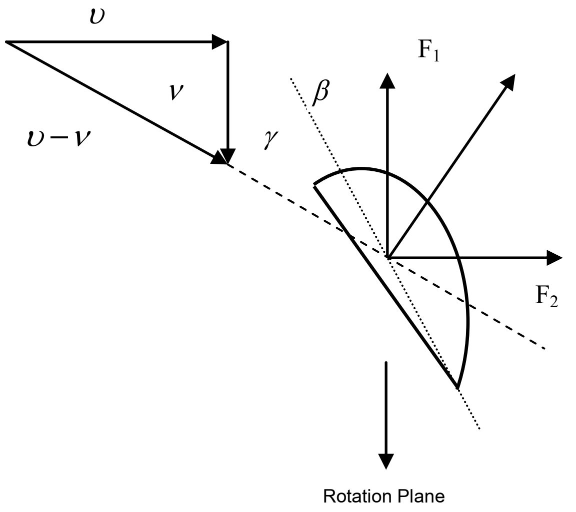


Fig. 8.2 Influence of air flow on wind turbine blade

Air flow influences on blade with a force (see Fig. 44) is defined as

$$F = C_v \frac{A\rho}{2}(\upsilon - \nu)^2,$$

where C_v is aerodynamic factor depending on the angle of attack. Correspondingly, wind plant engine's power is defined as

$$P_{out} = F \times \upsilon = C_v \times \frac{A\rho}{2}(\upsilon - \nu)^2 \times \nu,$$

where υ is wind velocity, ν - rotation velocity of the blade, $\upsilon - \nu$ - relative velocity of wind, γ - angle of attack, β - pitch angle, F_1- useful component of lift force, F_2 – rotor thrust

Specific speed is defined as rotor's blade-tip velocity to wind velocity i.e. $R\omega/\upsilon$, where ω is rotor's angular velocity. Operational values of specific speed coefficient are in the range from 4 to 12, and the optimal value is close to 8.

The output power extracted by wind turbine from air flow is defined with help of C_p as follows:

$$P_{out} = c_p(\upsilon, \omega, \beta) \times \frac{A\rho\upsilon^3}{2},$$

where C_p is coefficient of performance. The link between C_p and C_v is expressed as:

$$C_p = C_v \times \left(1 - \frac{\nu}{\upsilon}\right)^2 \times \frac{\nu}{\upsilon}:$$

The ratio of average power P_{avg} to rated power P_r is defined as Capacity Factor or coefficient of use of rated power:

$$P_{avg} / P_r = CF$$

8.3 Wind Power Plant Technologies

Fig. 8.3. Vertical axis wind turbine

Fig. 8.4. Off-shore greed-connected WPP with horizontal axis wind turbine

Wind power plants (WPP) are classified as per operation principles, design, rotor specific speed, capacity, target application. Depending on the orientation of rotor rotation axis with regards to air flow direction wind turbines are classified into two fundamental types: vertical axis wind turbine (VAWT) shown in Fig. 8.3 and horizontal axis wind turbines (HAWT) shown in Fig.8.4.

Depending on the specific speed of rotation wind turbines are classified into low-speed (multi blade) wind turbines (see Fig. 8.5), that are used in combination with mechanical equipment (pumps, mills) and high-speed wind turbines that are used for electricity production. A lot of designs were developed during past years: Savonius rotor (vertical axis), Darrieus rotor (vertical axis), Musgrove rotor (vertical axis), Evans turbine, etc. Wind power plants are classified into four categories according to power capacity of wind turbines (Table 8).

Operation of wind turbines is based on lift (for most of modern wind turbines) or resistance (draw) principles (low-speed turbines). In the first case wind flow passing over rotor blades produces lifting force, which makes the rotor turn around. This effect is similar to lifting force raised in airplanes. By applying lifting principle 59% power output can be reached (modern wind turbines achieve 50% efficiency at the optimum), while by applying resistance principle only 12%.

Table 8. Categories of wind farms as per capacity. Market segments: Source EWEA 2002

Market segment	Type of application	Installed power
A	Onshore, grid-connected wind farms	>1.5 MW
B	Offshore grid-connected wind farms	>1.5 MW
C	Onshore grid-connected wind farms	0.5-1.5 MW
D	Onshore decentralized turbines for weak grid hybrid/stand-alone operation	0.1-500 kW

Wind plants of low capacity are used to pump water in irrigation, communication areas, to charge electrical batteries, etc. Combined wind-solar and wind-diesel sets that allow produce electrical energy smoothly as much as possible within the year are also of high interest.

8.4 Energy Production Costs and Prices

Fig. 8.5. Low-speed (multi-blade) WPP

For wind turbine with capacity of 50W the costs of 1 W is 8 USD, while for photovoltaic module 1 W costs 5 USD. For this reason for small loads the use of photovoltaic is more preferable. For wind turbine with capacity of 300W the costs of 1 W is 2.5 USD, while for photovoltaic module 1 W costs again 5 USD. For wind turbines with capacity of 1500 W and 10000 W the costs for 1 W are 2 USD/W and 1.5 USD/W. With that costs for control equipment and regulators are the same: The same are the costs of tower and for photovoltaic modules. For wind power plants of large capacity the prices are based on 700-800USD/W rate. The cost of 1 kWh of electrical energy produced at wind power plant is estimated within 5-12 cents.

8.5 Industry of Wind Power Plants and Employment

Information on top 10 wind turbine manufacturers in Europe market is brought in Table 9.

Table 9. Information on wind turbine manufacturers

Company	Country	Sales, 2001 (MW)	Number of employees, 2001	European market share, %
Vestas	Denmark	1630	5500	23.3
Enercon	Germany	989	4100	14.1
NEG Micon	Denmark	875	1805	12.5
GE Wind	USA	861	1500	12.3
Gamessa	Spain	649	1114	9.3
Bonus	Denmark	593	500	8.5
Nordex	Germany	461	725	6.6
MADE	Spain	191	n/a	2.7
Mitsubishi	Japan	178	n/a	2.5
Repower	Germany	133	300	1.9

Data on direct employment in wind turbine manufacturing industry indicate that Spain, Germany and Denmark together account for 90% jobs, while other counties (UK, France, Portugal, Austria, Italy, and Netherlands) account for 10%. In 2001 wind industry of Europe represented 70 000 jobs (EWEA): According to different expert estimates, in 2020 in EU this figure will in the range from 1.25 to 1.8 million jobs.

8.6 Environmental Impact

Factors of impact on environment: audio-frequency waves and noise, interference of electromagnetic waves, collisions with birds, territory allotment for wind power plants, visual intrusion into landscapes, impact on birds and electromagnetic interference.

The noise is usually arisen (i) from tips of rotating blades (high-frequency noise), (ii)at the moment while blades move close to tower elements (low-frequency noise), (iii) from mechanical equipment, especially from gear.

The critical intensity of noise is 40 dB and these values are received at a distances of less than 250 m from large-scale wind power plants.

As a whole, among applied up-to-date technologies wind energy technologies' environmental impact is the lowest and lies within permissible range.

8.7 Wind Energy Use in Armenia

Wind energy theoretical potential in Armenia is estimated as 10 billion kWh annually, and technically available potential as 1.6 billion kWh (for capacity factor of 15%). According to expert estimations, economically feasible wind energy potential totals 500-600 million kWh, and rated power totals 500-600 MW.

In 1991, 4 small wind power installations (capacity each up to 4kW) were in operation at the Aragatsotn polygon. At the same polygon greed-connected wind power plant manufactured in Japan of 150 kW capacity was installed that is currently out of operation. In 1991, low-speed wind-driven water pump with capacity of 3-4l/s was installed in v. Derek [14, 47].

Fig. 8.6. Lori-1 wind power farm

To investigate wind energy resources in several areas of Armenia, ArmNedWind program had been implemented in 1999-2002 with funding from Netherlands government. 5 wind monitoring station shad been installed at Pushkin, Selim, Karakhach passes, in v. Artanish and at lake Arpi.

In 2006, Lori-1 wind power farm that includes 4 wind turbines each with capacity of 650kW (manufacturer-VESTAS company, Denmark) were installed at Pushkin pass in Armenia with funding from Iran Islamic Republic (see Fig. 8.6). Wind power plants are greed connected and operate in joint regime. The total capacity is equal to 2.6 MW. In 2008 Lori-1 produced 1.8 million kWh of electrical energy.

8.8 Wind Energy Resource Atlas of Armenia

In 2003, Wind Energy Resource Atlas of Armenia was developed by Renewable Energy National Laboratory (NREL) in collaboration with SolarEn International Corporation, and its Armenian subsidiary SolarEn LLC with funding from US AID. The Atlas was published in hard copy, as well as on CDs and is available through Internet [8]. During development of the Atlas both data from Armhydromet's 66 monitoring stations for several years at the height of 10m, and data from monitoring stations installed by SolarEn LLC were used. An advanced automated wind mapping techniques, developed at NREL that uses Geographic Information System (GIS) allows producing annual average wind resources maps with resolution of $1km^2$.

Data on wind power classification are brought in Table 10. Average wind speed is estimated for altitudes of 2000m and Weibull distribution of wind speeds. Shape factor k is equal to 2. Depending on wind speed actual distribution and actual elevation of sites actual average wind speed may differ from these values within 20 % [8].

Table 10. Wind power classification

Class	Resource potential (utility scale)	Wind power density (W/m^2)	Wind speed (m/s) at altitude of 50 m
1	Poor	0-200	0.0-6.0
2	Marginal	200-300	6.0-6.8
3	Moderate	300-400	6.8-7.5
4	Good	400-500	7.5-8.1
5	Excellent	500-600	8.1-8.6
6	Excellent	600-800	8.6-9.5
7	Excellent	>800	>9.5

Wind resource distribution in Armenia classified as per Table 10 is presented on the Map in Fig. 8.7 [8]. Most perspective regions for grid-connected wind energy plants are taken in circles. Estimations of wind resources from good to excellent at the elevation of 50m are brought in the Table 10.
According to Table 11, for average wind speeds related to class 7 it is possible to install wind power plants with total capacity of 500MW, and for average wind speeds related to classes 4-7 – up to 4900MW with assumption that installed capacity per $1km^2$ is 5MW.

Table 11. Good-to-excellent wind resources at the altitude of 50 m [8]

Wind Resource Utility Scale	Wind class	Wind Power at 50 m, W/m^2	Wind speed at 50m, m/s	Total area, km^2	Percent Windy Land	Total Capacity Installed, MW
Good	4	400-500	7.5-8.1	503	1.8	2500
Excellent	5	500-600	8.1-8.6	208	0.7	1050
Excellent	6	600-800	8.6-9.5	165	0.6	850
Excellent	7	>800	>9.5	103	0.4	500
Total				979	3.5	4900

Table 12. Moderate-to-excellent wind resources at the altitude of 50 m (utility scale) [8]

Wind Resource Utility Scale	Wind class	Wind Power at 50 m, W/m^2	Wind speed at 50m, m/s	Total area, km^2	Percent Windy Land	Total Capacity Installed, MW
Moderate	3	300-400	6.8-7.5	1,226	4.3	6150
Good	4	400-500	7.5-8.1	503	1.8	2500
Excellent	5	500-600	8.1-8.6	208	0.7	1050
Excellent	6	600-800	8.6-9.5	165	0.6	850
Excellent	7	>800	>9.5	103	0.4	500
Total				2205	7.5	11050

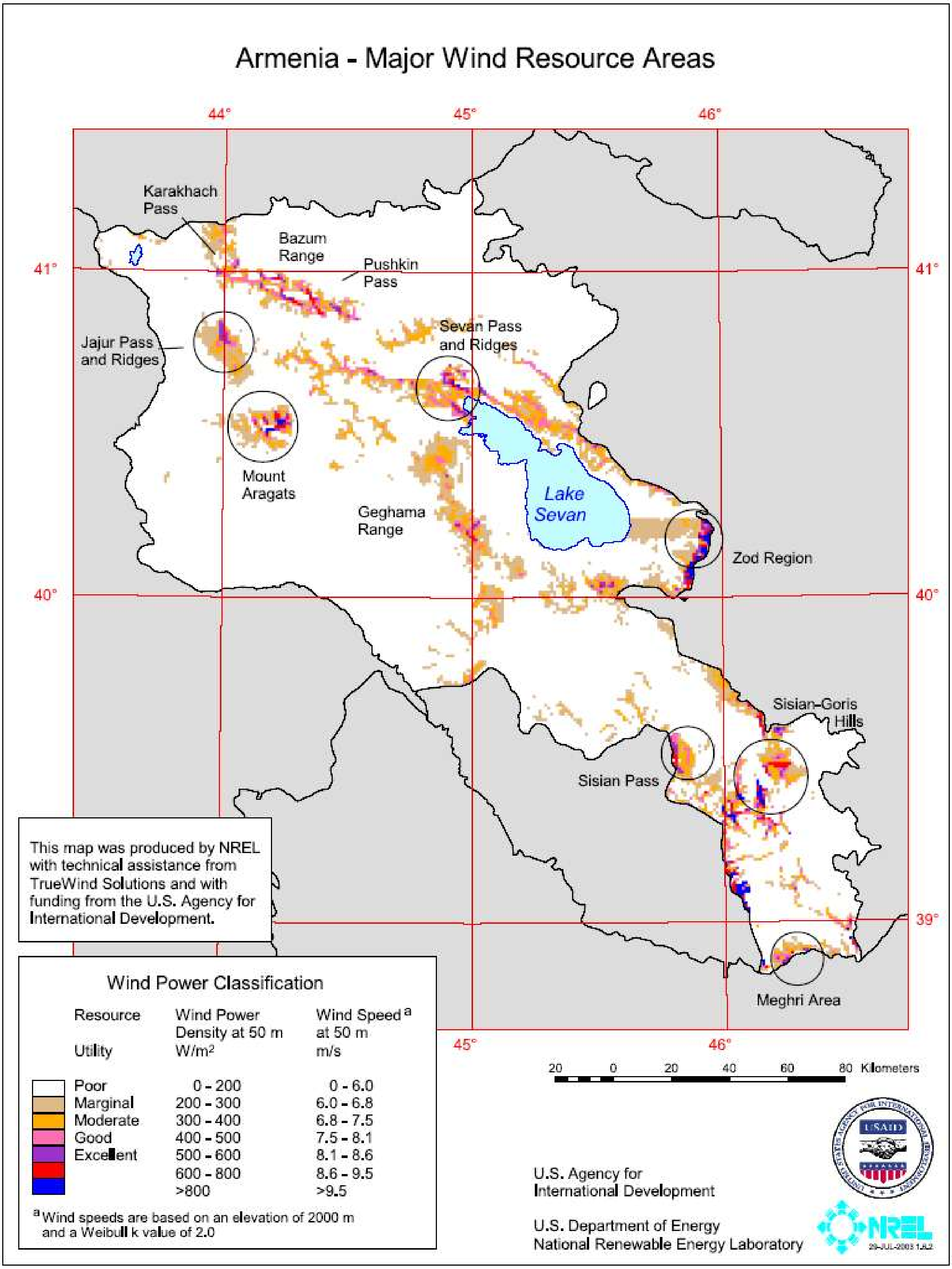


Fig. 8.7. Armenia – Major wind resource areas [8]

CHAPTER 9 GEOTHERMAL ENERGY

Fig. 9.1. Deposit of dry steam

9.1 The Nature of Geothermal Resources

The Earth was formed 4.7 billion years ago. It consists of crust with depth of 20-65km under continents, and of around 5-10km under oceans, mantle with depth of 2900km and core with radius of around 3470km.

Mean geothermal gradient in the crust is 2.5-3°C/100m. So it can be concluded that at the depth of 2000m the temperature will reach 65-75°C, at 3000m - 90-105°C. But there are large zones for which the values of vertical gradient might be less than 1°C/100m, as well as ten times as much as mean geothermal gradient.

The total thermal energy of the earth is estimated at around of 12.6 x10^{24} MJ, and of the crust - 5.4 x 10^{21} MJ. Heat is continuously produced in the core of the Earth due to decay of uranium, thorium and other long-lived radioactive isotopes. The maximum temperature of the core is within 5000-6000°C. Theoretically, the Earth is gradually cooling, but this process is going on at very low rate. During three billion years the temperature of the mantle was decreased by 300-350°C, and now it is around 4000°C.

Geothermal resources are classified into petro-geothermal (heat of dry hot rocks) and hydro-geothermal resources. The lasts are present in the form of natural heat carriers: steam, steam-water mixture, and hot water. With respect to thermal energy potential, geothermal resources are classified into geothermal resources with low (less than 75^0C), mean (75-150^0C), and high potential (more than 150^0C).

Up to now geothermal energy is extracted if heat carrier is available in the form steam or hot water through which the heat from hot zones located at appropriate depth is transferred to the surface zones or close to them of the Earth. New perspectives are anticipated in the near future with introduction of innovative technologies, particularly in the area of utilization of the heat of hot dry rocks.

9.2 The Current Status of Geothermal Energy Utilization.

The total capacity of geothermal power plants was 8.9GW_{el} in 2004, 9.5GW_{el} in 2006, and 10GW_{el} in 2008 [6].

The technologies to produce electricity are as follows:

Fig. 9.2. The largest geothermal power plant with capacity of 665 MW in Geysers, USA (1980) [1, 28]

a. **Flash steam power plants** (5-100MW_{el}) are the most common type of geothermal power plants. The steam is separated from the water, and then is piped to power house to drive the steam turbine. After leaving the turbine the steam is condensed and create partial vacuum. As a result, maximum power is generated by the turbine-generator.

b. **Binary cycle power plants** (500kW_{el}-10MW_{el}). This type of power plants is used when the temperature in reservoirs is within 100-220^0C. The fluid from reservoir in the form of steam or water, or both passes through heat exchanger and heats working fluid, usually, an organic fluid (isopentane or isobutane) with boiling temperature less than 100^0C. The organic fluid is vaporized and drives the steam turbine.

c. **Combined cycle (flash and binary) geothermal power plants**. This type of plants is a combination of conventional steam turbine technology and Binary cycle technology.

The cost of electricity production is 7-15 Eurocent/kWh. The prices per unit of installed capacity depend on size of plants. Their estimates are brought below [4,5].

	Capacity, MW	Specific values, Euro/kW
1.	10-15	1200-1300
2.	25-30	875-1050
3.	55	600-850

9.3 Heat Pumps

Heat pump was invented by Britain physicist William Thomson. 1.5 century ago he named the invented device or machine as "heat multiplier". By help of heat pump the heat is transferred from the source with lower temperature to the source with higher temperature. Heat pumps provide heating, cooling, or both together. There are two types of heat pumps: closed circle heat pumps that extract the heat from loop of pipes installed at some depth under the earth surface, and open circuit heat pumps that utilize the heat of underground waters. During operation of heat pump 2.5-5 kWh of heat energy is produced against each kWh of energy consumed by compressor. The ratio of thermal energy produced to electrical energy consumed is called coefficient of transformation, and it characterizes the effectiveness of heat pumps.

Fig. 9.3. Heat pump: heat of a ground not at a great depth is used [4]

By the end of 2004, total installed capacity of heat pumps was equal to 15GW. 355837 heat pumps were installed in EU as of 2002, particularly in Sweden - 170000, in Germany - 3455, in France - 36500:
Capacities of heat pumps are within 1kW -1MW, and costs of thermal energy produced are 15-20 cent/kWh.

9.4 The Prospects of Geothermal Heat Use in Armenia

According to expert estimates, geothermal resources in Armenia have enough high potential of 584PJ ($584x10^{18}$ Ջ). Among areas with high petro thermal regimes there were investigated south-western part of the Lake Sevan and north-eastern part of Syunik (Jermaghbyur and Angeghakot sites). According to Jermaghbyur borehole data the temperature of rocks is equal to 99^0C at the depth of 920m. At the depth of 2-2.5km the temperature of rocks can reach $250\text{-}300^0$C.

In the frames of the program "Assistance to Armenia" in 1998 GeotherEx company prepared report on geothermal resources in Armenia according to which among 18 zones were research works were implemented the most interest was attracted to the following areas: Martuni (T_{max}= 40^0C)[1], Jermuk (T_{max}= 63^0C), valley of r. Vorotan (T_{max}= 43^0C), Hankavan (T_{max}= 42^0C), Arzakan (T_{max}= 45^0C).

Nowadays hydro-geothermal resources (mineral thermal waters) are used in miserable volumes for health treatment purposes.

[1] Maximum temperatures are brought in parenthesis

Data on hydro-geothermal resources in Armenia as per National Program on Energy Saving and Renewable Energy (2007) are brought in the Table 13 below [16].

Table 13. Hydro-geothermal energy potential in Armenia [16]

Area	Low potential t < 100°C	High potential t > 100°C	Depth, M	Thermal potential, 1000 GCal/year
Jermuk	64		>300	12.7
Jermuk	47.5			
Hankavan	42		>400	20
Hankavan	36[2]			
Arzakan	54	-	>800	5.5
Martuny	52	-	>800	22
Sisian	45		1100	101
Sisian	37[2]			
Sevaberd	83	-	3100	25.2**
Azatavan	42		2600	**
Mkhchyan	-	-		0,6
Kechut	31.6			
Artashat	41			**
Ptghny	60			
Near Yerevan	79		2500	0.49 million GJ
Near Yerevan	70[2]		2400	
Near Yerevan		110-125[2]	4000	
Jermaghbyur		115-310	1000-2500	>

* Research works are not completed

** High concentration of minerals

9.5 Description of Projects in Armenia

According to results of "Jermaghbyur geothermal power plant feasibility study" prepared in frames of GEF/WB TF 053910 program in 2006 by Ameria LLC, for Flash type geothermal power plant with installed capacity of 25 MW required investments should be in the amount of 17.6 billion AMD and specific costs per 1 kW of installed capacity should be 1564USD [9]. Annual average electricity production was estimated as 199.4 million kWh. It was required 6 production boreholes with depth of 3km and 2 boreholes with depth of 3km for return flow. Minimum temperature of geothermal resources at the depth of 2500-3000m is estimated as 250^{0}C. These results are based on results of research works carried out by different teams groups and obtained data over last years. Before that research of this site was done in frames of GEF/WB programs. Nowadays, the right to implement this project belongs to private investor.

In the report "Identification of perspective high-potential geothermal zones" (2007) prepared under the contract with R2E2 Fund of Armenia, as perspective zone with high-potential of geothermal resources (more than 100^{0}C) was proposed the zone of Eratumber young (Holocene period) volcanoes group in the north-eastern part of Geghama volcano mountain plateau in the Central part of territory of Armenia.

Gridzor and Karkar zones were selected as high-potential perspective geothermal zones in 2009 to conduct researches with funding from government of RA.

Research works on heat pumps utilization in Armenia were summarized in "Assessments of Renewable Energy Resources in Armenia" report prepared by AEAI Inc. with funding from USAID in which perspective sites are described in detail (2002). In Armenia, only air source heat pumps are used, and they are imported from abroad. Since the source of heat in these devices is outside air, so their coefficient of performance is strongly reduced with temperature decrease in winter when the ambient temperature is low. For example, for -18^{0}C of ambient temperature their COP is close to 1.

9.6 Impact on Environment

During the utilization of geothermal energy there are some definite impacts on environment. For those plants when geothermal fluid is extracted from depths of earth and then is returned back to the depth pollutant emissions are very small. Several boreholes (well) are required for typical geothermal plant. Though boring works affect on the lands, but if slanted bore-hole is used then impacts can be reduced to minimum. That allows to receive several bore-holes from one boring site and to reduce number of boring sites, number of roads leading to boring sites and number of pipelines for geothermal waters.

Environmental problems might arise also during operation of plant. The used heat carrier - steam or water, generally, contains CO_2, H_2S, NH_3, CH_4 and traces of other gases, as well as dissolved substances whose concentration is raised with temperature. For example, NaCl, B, As, and Hg are sources of pollution when they are emitted in the environment. Thermal pollution is also harmful for ecosystems. To reduce this type of impact the utilized waters should be cooled in specially constructed reservoirs before being discharged into natural reservoirs. Nevertheless, application of the up-to-date technologies allows reducing impact on environment to minimum.

CHAPTER 10 SMALL HYDRO POWER ENGINEERING

10.1 Hydro Energy Potential in Armenia

The theoretical potential for hydropower resources of Armenia has been estimated as 21.8 billion kWh/year. It includes 18.6 billion kWh/year for large and medium rivers, and 3.2 billion kWh/year for small rivers. Technically available potential is estimated around 7-8 billion kWh/year, and economically feasible potential – 3.2-3.5 billion kWh/year [46]. Hydropower plant with capacity less than 10MW is considered as Small Hydropower Plant (Small HPP).

In 1903, the first hydropower plant with capacity of 75 kW (micro HPP) was constructed on the river Vokhchi in Armenia [47].

In 1991, "The Scheme of Development of Small Hydropower Engineering" was composed by Armhydroenergyproject Institute that revealed technical possibility to construct 371 small HPPs with total capacity of 392MW and annual power production of 1178 million kWh.

In 1997, according to "The Scheme of Small Hydropower Plants of Armenia" developed by Institute of Armhydroenergyproject within INCO program and by order of CEEETA (Portugal) it has been envisaged to construct 325 small HPPs instead of 371 as in previous scheme with total capacity of 274 MW and average annual electricity generation of 833 million kWh. 38 most feasible and attractive for the investments small HPPs with total capacity of 70 MW were selected [46].

It is notable to mention that in 2002 only 29 small hydropower plants were in operation with total capacity of 42.8 MW and average annual electricity generation of 107 million kWh (the Dzora HPP with capacity of 26.5 MW is not included in the list). Of all 24 small HPPs constructed before 1957, 13 HPPs were privatized in late 1997, 8 HPPs – were written off. From 1997 to 2002 11 new HPPs have been constructed, 10 of them - privately. 11 private HPPs were under construction (total capacity 25.5MW) [48].

Development of hydropower resources including small hydropower has being planned Armhydroenergyproject Institute in the following way [46]. Among the most large-scale waterways of Armenia still unexploited are the Debed River with the Dzoraget tributary and the Arax River. As a whole it was planned to construct several large and medium HPPs with total capacity of 259 MW and annual average electricity generation of 1.1 billion kWh

In 2008, the Update of the existing scheme for small hydro power plants of the Republic of Armenia was prepared by Armhydroenergydesign Institute by order and with funding from R2E2 Foundation[51].

According to data from Armhydroenergydesign Institute as of 2008 [50], the used hydro potential of Armenia was 1060 MW with annual average power generation of around 1.8 billion kWh, including small HPPs with capacity of 75MW and power generation of 244 million kWh.
Technically available and economically feasible unused hydro potential is 500MW with annual average power generation of around 2.1 billion kWh. It includes:

- Large HPPs with total capacity of 270MW (Meghry HPP - 130MW, Loriberd HPP - 65MW, Shnokh HPP - 75MW) and annual average power generation of around 1.3 billion kWh;
- Medium HPP (Pambak) with capacity of 20MW and annual average power generation of around 79 million kWh;

- Small HPPs under construction with total capacity of 60MW and annual average power generation of around 200 million kWh;
- Small HPPs according to updated scheme of HPPs (2008) [51] with total capacity of 147MW and annual average power generation of around 540 million kWh.

In 2009, electricity generation by all hydropower stations in Armenia (6 hydropower plants with capacity of 556 MW of the Sevan-Hrazdan Cascade, 4 HPPs with capacity of 405.2 MW of the Vorotan Cascade, the Dzora HPP with capacity of 26.5 MW, and all small HPPs with capacity of 90 MW) totals 1,991.1 million kWh/year. In 2009, the share of small HPPS in total power production totaled 5.65%.

Table 14. Power production in RA in 2009 (based on data received from PSRC of RA)

Name of the power plant	Power production	
	mln kWh	%
Thermal power plants (TPP)	1053.07	19.7
Metsamor Nuclear power plant (MNPP)	2290.44	42.9
Large and medium hydropower plants (HPPs)	1693.51	31.7
Small hydropower plants (small HPPs)	297.63	5.6
"Lori 1" Wind Energy Plant	3.91	0.1
"Lusakert Biogas Plant"	2.69	
Total power production	5341.3	100

10.2 Design and operation of small HPP

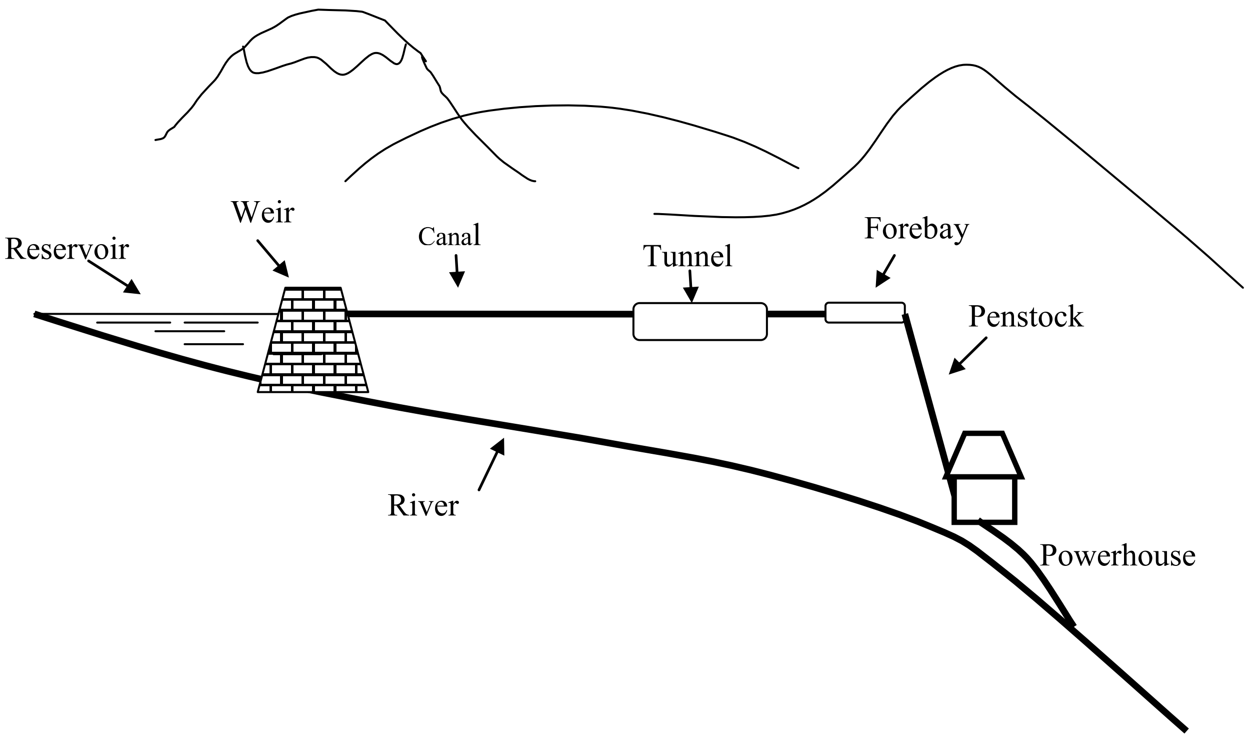


Fig. 10.1. Typical layout of small HPP

Typical layout of small HPP is presented in fig. 10.1. Water from the river is diverted by weir (small reservoir might be or not) and flow through canal, tunnel to forebay, from where penstock or pressure pipeline conduct the water to the turbine in the power house. Dams are rarely used in small HPP schemes since their construction are expensive. Another scheme is to install power plant on existing conventional dam constructed for irrigational purposes.

Under assumption that overall efficiency of electromechanical equipment is 0.81, the power extracted is defined as P = 8 QH, where Q is discharge (m3/s), H is net head (m) [52].

Electromechanical equipment includes hydraulic turbines, gear boxes and other speed increasers, generators, control equipment. Hear we provide short description of hydraulic turbines only. For other equipment component the reader can retrieve information available in special literature [52], from manufacturers and Internet sites.

Hydraulic Turbines

Hydraulic turbine is a rotating machine that converts the potential energy of the water to the mechanical energy. There are two basic types of hydro turbines [52]: active (impulse) and reactive. In reactive type turbine the runner of turbine is completely immersed into the water and is rotated mainly due to the pressure's difference before and after the runner. Kaplan and Francis turbines are examples of reactive type turbines. In active type turbine the water pressure is first converted into kinetic energy in the form of a high speed jet(s) that strike the buckets, mounted on the periphery (rim) of the runner. The runner is rotated in the air in active type turbine. Pelton turbine is an example of active (impulse) turbine.
Hydraulic turbines are grouped in three categories [52]:

- Kaplan and propeller turbines,
- Francis turbines,
- Pelton and other impulse turbines.

Propeller turbines and Kaplan turbines (the most widely used of the propeller-type turbines) are axial-flow reaction turbines (see Fig. 10.2a, b). Kaplan turbine was developed in 1913 by the Austrian professor Viktor Kaplan, who combined automatically-adjusted propeller blades with automatically-adjusted wicket gates to achieve efficiency over a wide range of flow and water level [52]. They are generally used for low heads (see Table 10.1). Kaplan turbine has adjustable runner blades. In case of adjustable blades and guide vanes, it is referred to as double-regulated turbine, and in case when guide vanes are fixed it is referred to as single-regulated turbine. Several other variations of propeller-type turbines are as follows: Bulb or Tubular turbines, Pit turbines, Straflo turbines, S- turbines, VLH turbine, Tyson turbines.

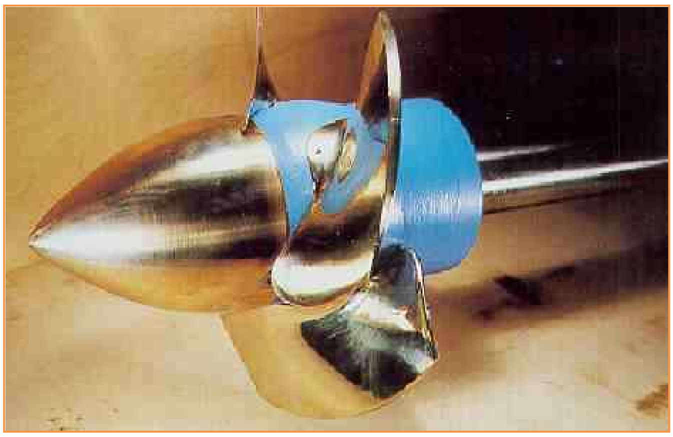
Francis turbines (Fig. 10.2d) are radial flow reaction turbines with fixed runner blades and adjustable guide vanes. They are generally used for medium heads (see Table 10.2).

Pelton turbines (Fig. 10.2c) are impulse turbines with single or multiple jets, each jet issuing through a nozzle with a needle valve to control the flow. They are used for medium and high heads (see Table 15).

In addition to above-mentioned widely spread group of turbines, there are special types of turbines used in HPPs: Cross-flow turbines (sometimes called Banki or Mitchell turbines), Turgo turbines, and reverse running pumps.

Cross-flow turbines, also known as Ossberger turbines (Ossberger is name of company that manufactured this type of turbines for more than 50 years) are impulse turbines, and used for wide range of heads (see Table 15). The runner is built from two or more parallel disks that are connected near their rims by a series of curved blades.

Turgo turbines are impulse ones and are used for head in the range 50-250m. The buckets of Turgo turbines are shaped differently and jet of water strikes the plane of the runner an angle of



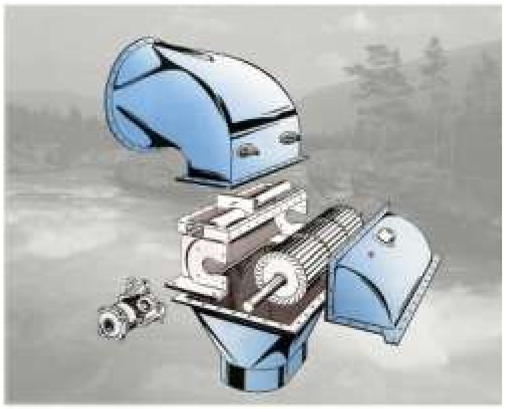
(a) Propeller turbine

(b) Kaplan Turbine

(c) Pelton Turbine

(d) Francis Turbine

(e) Turgo Turbine



(f) Cross-flow (Ossberger) turbine

Fig. 10.2. Different types of hydraulic turbines: a - Propeller turbine, b - Kaplan Turbine, c- Pelton Turbine, d- Francis Turbine, e- Turgo Turbine, f- Cross-flow (Ossberger) turbine.

20^0. The structure of a Turgo wheel is much like that of airplane turbine in which the hub is surrounded by a series of curved vanes. These vanes catch the water as it flows through the turbine causing the hub and shaft to turn.

Conventional **centrifugal pumps** can also be operated as turbines. Water flow is directed through outlet of pump to inlet. They shall be operated under relatively constant head and discharge since they have no flow regulation.

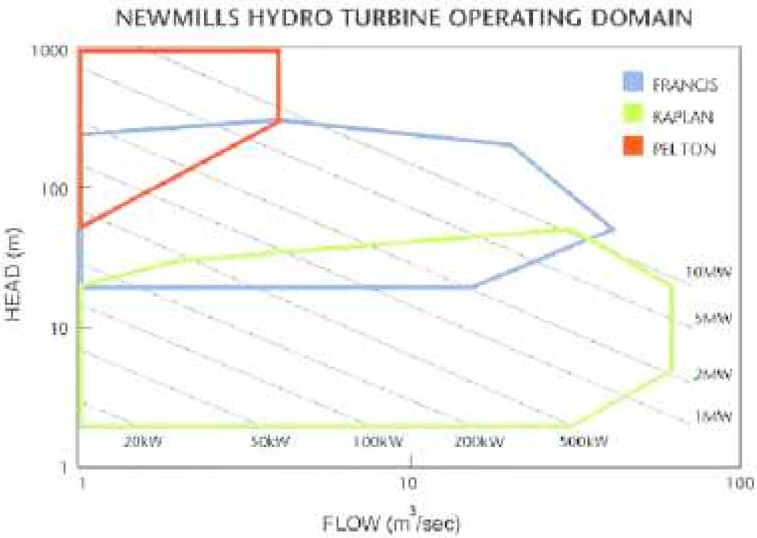
Table 15 illustrates range of characteristic heads for which different types of turbines are generally used. Table 16 illustrates typical efficiencies of turbines for small HPPs. Typical operating ranges (water discharge and head) for different types of turbines are brought in Fig. 10.3-10.4.

Table 15. Range of Heads [52]

Types of turbine	Range of heads H, m
Kaplan and propeller	$2 < H < 40$
Francis	$25 < H < 350$
Pelton	$50 < H < 1300$
Cross-flow	$5 < H < 200$
Turgo	$50 < H < 250$

Table 16. Typical efficiencies of turbines for small HPPs [52]

Turbine type	Best efficiency
Kaplan single regulated	0.91
Kaplan double regulated	0.93
Francis	0.94
Pelton n nozzles	0.90
Pelton 1 nozzle	0.89
Turgo	0.85



• Fig. 10.3. Typical operating ranges (water discharge and head) for different types of turbines: Kaplan and propeller turbines, Francis turbines, and Pelton turbines manufactured by Newmills Corporation

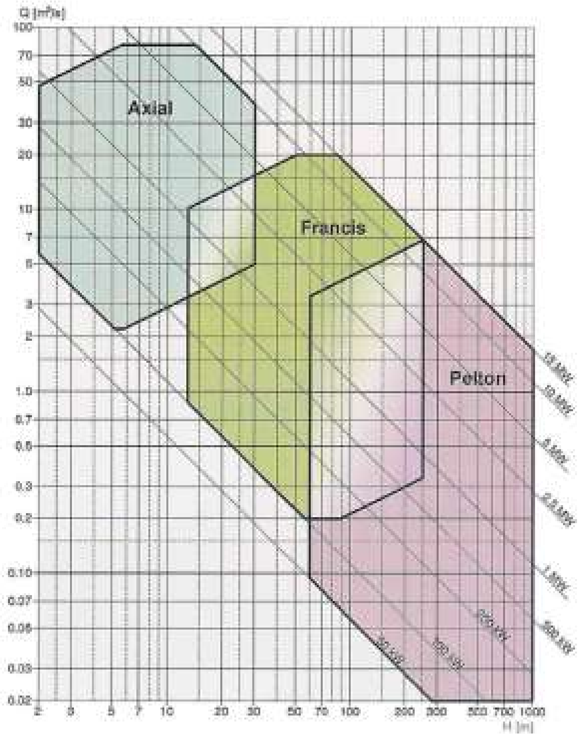


Figure 10.4. Turbines' type field of application [52]

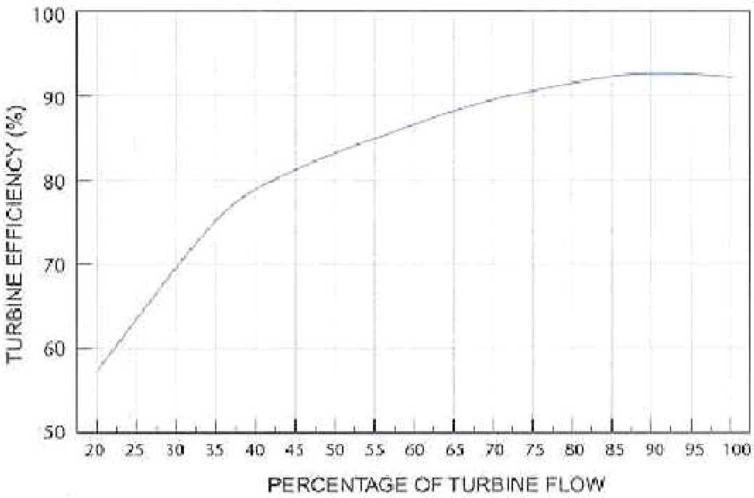


Fig. 10.5. Francis type turbine efficiency curve

It is defined as the ratio of power supplied by the turbine (mechanical power transmitted by the turbine shaft) to the hydraulic power.

As defined in Fig. 10.4, the turbine efficiency is not only limited to the runner. International standards clearly define the limits of the turbine and the manufacturer must give its guarantees according to these limits. The manufacturer also indicates quality criterion that the owner has to respect, such as velocity repartition and flow deviation at the intake in the case of low head schemes.

Fig. 10.6. Power house of small HPP on tributary of Elegis river (2008)

a

b

Fig. 10.7. Zovashen small HPP: a) powerhouse with turbines (view inside), b) pressure pipeline and powerhouse (view outside).

Fig. 10.8. Aygedzor-2 small HPP

Fig. 10.9. Frencis type turbine manufactured in Armenia by Vorotan LLC

One of good examples of renewable energy sources (RES) applications in Armenia is “Turbo pump” installed on the irrigation pipeline of Azat water reservoir (Artashat Marz) to pump waters by around 100m upward with purpose to provide the Landgazat village with irrigation waters (see Fig. 10.10). Turbo pump doesn’t use electricity and pumping effect is reached when water flow put into rotation the turbine which in its turn operates water pump. The turbo pump has been in operation around 6 years. This experience is desirable to replicate in other sites through Armenia.

Fig. 10.10. Turbo pump manufactured in Armenia by Vorotan LLC

10.3 Impact on Environment

Impacts of small HPPs on environment can be grouped in 4 categories:

- Impact on the landscape
- Sound impact
- Biological impacts
- Water quality

Each of the components of small HPP – power house, weir, spillway, penstock, intake, tailrace, substation, and transmission lines may create a change in the visual impact of the site through introduction of contrasting forms, lines, color or textures. Most of these components can be screened from the view through the use of landform and vegetation.

Noise level can be minimized by improving the hydrodynamic design and by covering the shell with acoustic insulation.

Regarding the biological impact of small HPP, then most schemes, especially in mountainous areas, are of diversion types, i.e. reservoir is usually not used. Water is diverted from the river to power plant might be kilometers away from the diversion point to take advantage of higher head. A great variety of fishpass designs has been developed to reduce impact on spawning, incubation, rearing and passing of fish (see Fig. 10.11, 10.12). Nevertheless this issue continues to raise anxiety among public and requires additional financing while constructing HPP.

Since most small HPPs don't have reservoirs and don't store water in it, then these small HPPs don't cause changes in water quality such as higher temperatures, low oxygen, decreased food production etc.

Fig. 10.11
Fish pass of rustic construction [52]

Fig. 10.12
Fishpass with vertical slots [52]

Glossary

- intake shaft - a tube that connects to the piping or penstock which brings the water into the turbine
- water nozzle - a nozzle which shoots a jet of water (impulse type of turbines only)
- runner - a wheel which catches the water as it flows in causing the wheel to turn
- generator shaft - a steel shaft that connects the runner to the generator
- generator - a small electric generator that creates the electricity
- exit valve - a tube or chute that returns the water to the stream it came from
- powerhouse - a small shed or enclosure to protect the water turbine and generator from the elements.

CHAPTER 11 PROMOTION POLICIES FOR RES USE

Basic mechanisms to promote RES development are: (a) feed-in tariffs to purchase energy generated, (b) renewable portfolio standard (RPS) i.e. establishment of standard of minimum amount of energy produced by renewable energy sources in total amount of energy produced: In 2008, RPS was in operation in 49 countries, states, and provinces and feed-in tariffs in 45 countries and 18 states and 18 provinces. Different types of promotion policies to generate renewable power that were mostly appropriate to countries needs were used in 64 countries by beginning of 2009.

According to assessments conducted in [6], 120 billion USD was invested in the development of RES in 2008, i.e. twice the amount invested in 2006. Most of the investment increase was allocated as follows: wind power – 42%, solar PV - 32%, and bio-fuels - 13%. In addition, 40-45 billion USD was invested in large hydropower stations. Many banks continued to provide loans for RES programs in 2008, particularly European Investment Bank (EIB) allocated 2 billion Euros (2.6 billion USD). In the end of 2008, several governments of states announced about sharp increase of state financing to be provided in the area of RES, low carbon emission or clear technologies development, particularly USA will provide 150 billion USD during 10 years, Japan – 12.2 billion USD during 5 years, Hungary- 330 million USD during 7 years, South Korean – 36 billion USD during 4 years.

11.1 Promotion Policies to Use RES in EU

In 2009, European Council approved the decision that the share of energy from RES in total energy consumption inside EU shall be 20% by 2020. In other decision 10% targets to reduce GHG emissions from transport fuel was established to be reached by 2020, of which 6% - obligatory. Since 2006 essential changes were introduced in feed-in tariffs in EU countries at national levels, in particular related to electrical energy generated by solar photovoltaic stations. In Italy feed-in tariff for electrical energy generated by solar PV stations is 36-49 Eurocent/kWh. Besides that, feed-in tariff for electrical energy generated by building incorporated photovoltaic stations is higher than for solar PV stations/equipment installed on the roof in traditional way by 5 Eurocent/kWh. In France feed-in tariff was increased up to 30 Eurocent/kWh, besides, feed-in tariff for electrical energy generated by building incorporated photovoltaic stations is additionally increased by 25 Eurocent/kWh. Depending on the size and/or place of PV installations, feed-in tariffs for electrical energy generated by them are 40-55 Eurocent/kWh in Greece, 32-49 Eurocent/kWh in Austria, 31-45 Eurocent/kWh in Portugal, 32-43 Eurocent/kWh according to new law (EEG 2009) in Germany.

11.2 Promotion Policies to Use RES in Armenia

Over last years, Public Services Regulatory Commission (PSRC) has conducted promotion policy based on feed-in tariff directed at development of renewable energy resources. The policy is supported on the following adopted decisions:

Decision No. 52N «On establishment of maximum tariff for electrical energy generated from biomass», dated September 2, 2001, according to which tariff in the amount of drams equivalent to 7 US cent/kWh (VAT is not included) for the first 7 years of operation of station was established.

Feed-in tariff in the amount of drams equivalent to 7 US cent/kWh (VAT is not included) was also established for electrical energy generated by wind power plant (WPP) by Decision No. 21N dated February 9, 2004.

Feed-in tariffs for small hydropower plants (small HHP) were approved as follows:

a) for small HPPs constructed on natural waterways tariff for generated electrical energy is adopted in the amount of drams equivalent to 4.5 cent (VAT is not included) per kWh (Decision No. 20N as of 09.02.2004,

b) for small HPPs constructed on drinking water pipelines tariff for generated electrical energy is adopted in the amount of drams equivalent to 2.0 cent (VAT is not included) per kWh (Decision No. 166N as of 08.11.2005),

c) for small HPPs constructed on irrigation structures tariff for generated electrical energy is adopted in the amount of drams equivalent to 3.0 cent (VAT is not included) per kWh (Decision No. 166N as of 08.11.2005),

Above mentioned tariffs are in force for 15 years starting from date of issue of electrical energy production license (Decision No. 166N and No.167N as of 08.11.2005).

Besides, in accordance with the appropriate changes approved in the Energy Law of RA, during 15 years starting the date of issues of construction license all the electrical energy generated at small HPPs is a subject of purchase in accordance with established procedure and market rules.

In 2005, PSRC adopted decision and established the rules of work for RES based generators with capacities of 100kW and less that operate in parallel with electrical network. According to that decision, generated power is used for generator's own needs and excess of energy is passed to electrical network for free. The same amount of energy is taken from electrical network by generator. Once a year the balance is brought to zero. According to revised decision as of 2006 limit of generator's capacity was increased up to 150kW, besides, these rules became applicable also to CHPs.

As we mentioned earlier, Armenia ratified UN Framework Convention on Climate Change (UNFCCC) in 1993 and Kyoto Protocol in 2003. As a developing country not included in the Annex I of the UNFCCC, Armenia has no quantitative obligations for greenhouse gas emission reduction. However, it undertakes voluntary obligations on the limitation of GHG emissions, with assistance of developed countries, within the frames of corresponding mechanisms of UNFCCC.

In particular, in frames of Clean Development Mechanisms (CDM) 12 projects are at different stages of development, of which in 6 projects it is planned to construct and operate 15 small HPPs and 1 wind power plant with total installed capacity of 58.8 MW, in two projects – heat and power generation from agriculture animal and municipal wastes [18].

Taking into account the importance of RES development in Armenia, in the last years several important decisions directed at the development of RES in Armenia were adopted:
- The Law of RA «On Energy Saving and Renewable Energy » adopted in 09.11.2004:
- "Energy Sector Development Strategy in the Context of Economic Development in Armenia" approved by protocol decision by the Government of RA as of 23.06.2005.
- «National Program on Energy Saving and Renewable Energy», approved by protocol decision No.2 by the Government of RA as of 18.01.2007

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LIST OF ABBREVIATIONS

NSS	National Statistical Service of RA
GEF	Global Environment Facility
EU	European Union
EE	Energy Efficiency
SD	Sustainable Development
MNPP	Medzamor Nuclear Power Plant
WB	World Bank
HPP	Hydropower Plant
PSRC	Public Services Regulatory Commission of RA
RA	Republic of Armenia
WPP	Wind Power Plant
R2E2F	Renewable Energy and Energy Efficiency Foundation of RA
IAEA	International Atomic Energy Agency
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
UNDESA	United Nations Department of Economic and Social Affairs
CDM	Clean Development Mechanism
Greenhouse gas	GHG
TPP	Thermal Power Plant
HP	Heat Pumps
RES	Renewable Energy Sources
toe	Ton of Oil Equivalent
tce	Ton of Coal Equivalent
Small HPP	Small Hydropower Plant
FAR	Fund for Armenian Relief

ENERGY UNIT CONVERSION COEFFICIENTS FOR DIFFERENT SYSTEMS OF UNITS

	TJ	Gcal	Mtoe	MBtu	GWh
TJ	1	238.8	0.00002388	947.8	0.2778
Mtoe	41868	10000000	1,00E+00	39680000	11630
MBtu	0.001055	0.252	2.52E-08	1	0.0002931
GWh	3.6	860	0.000086	3.412	1

Source: www.iea.org/stat.htm

Btu: Britain Thermal Unit

1 tce = 0.7 toe = 8141 kWh = 7 Gcal = 0.2931 TJ

Heat capacity of imported gas in Armenia in 2006

1000 m^3 of natural gas = 1.144 tcoe.

1 tce = 874.1 nm^3 of natural gas

RES RELATED INTERNET SITES IN ARMENIA

http://www.renewableenergyarmenia.am (EU-Armenia: renewable energy resources)
http://www.solaren.com (Solaria LLC)
http://www.technokom.am (Technokom LLC)
http://www.delarm.ec.europa.eu
http://www.minenergy.am (Ministry of Energy and Natural Resources of RA)
http://www.psrc.am (Public Services Regulatory Commission of RA)
http://www.mnp.am (Ministry of Nature Protection of RA)
http://www.nature-ic.am (Climate Change Information Center)
http://www.r2e2.am (Renewable Energy and Energy Efficiency Foundation of RA)
http://www.cch.am/index.cfm (Cascade Capital Holding)

RES Related International Internet Sites

http://www.nrel.gov (National Renewable Energy Laboratory, USA)
http://www.eere.energy.gov (U.S. DOE Energy Efficiency and Renewable Energy (EERE))
http://www.ren21.net (Renewable Energy Network 21)
http://www.eufores.org (The European Forum for Renewable Energy Sources)
http://www.erec-renewables.org (The European Renewable Energy Council (EREC))
http://www.eurec.be/projects/RE_barometer.htm (The European Renewable Energy Research Centres Agency bulletins)
http://www.managenergy.net (European Commission Directorate-General for Energy - ManagEnergy)
http://www.re-focus.net (Renewable Energy Focus: international renewable energy news, features etc.)
http://www.retscreen.net (RETScreen International)
http://www.inforse.org (INFORSE - International Network for Sustainable Energy)
http://cordis.europa.eu (Community Research and Development Information Service (CORDIS))
http://europa.eu.int/comm/europeaid/projects/index_en.htm (External cooperation programmes - European Commission)

ATTACHMENT 1

EFFICIENCY OF SOLAR THERMAL COLLECTORS

The efficiency of solar thermal collectors η_c is the ratio of heat Q_c delivered to working fluid to total incoming radiant solar energy on solar collector absorber surface, or

$$\eta_c = \frac{Q_c}{(E_c \times A_c)} \quad \text{(A1.1)}$$

where E_c [W/m^2] is incoming radiant solar energy per 1 m^2 of absorber surface of solar collector, A_c is the area of absorber surface [m^2]. Q_c is calculated as:

$$Q_c = mC_p(T_1 - T_2) \quad \text{(A1.2)}$$

where m [kg/s] is the discharge of working fluid, C_p [J/ (kg* s)] is specific heat capacity, T_1 and T_2 are the temperatures of working fluid at the input and output of solar collector.

Instantaneous efficiency η_c^{ins} is defined as

$$\eta_c^{ins} = \eta_0 - \frac{K_c \times (T_1 - T_{amb})}{I_c} \quad \text{(A1.3)}$$

where η_0 is effective optical efficiency of solar collector, K_c is effective coefficient of heat loss (in W/m$_2$^{0}C), T_1 is the temperature of working fluid at the inlet of solar collector, T_{amb} is the ambient temperature, I_c is solar irradiation (W/m^2).

The efficiency of solar collector is changed with changing of solar irradiation I_c, i.e. solar collector's average efficiency is significantly lower than the efficiency of solar collector registered at noon (the standard performance test's time period is of order of 15-20 min). With increasing of solar irradiation from 300 to 1000W/cm^2 then the efficiency of solar collector is increased from 32 to 59%, and with increasing of ambient air temperature from 10 to 30^{0}C then the efficiency is increased from 41 to 55%.

Optical efficiency of solar collector depends on the product of effective coefficient of transmittance of collector cover τ_c and absorption coefficient of absorption surface α_c (i.e. $\tau_c \times \alpha_c$) and doesn't depend on the solar irradiation I_c or temperature difference $(T_1 - T_{amb})$. The efficiency of solar collector is strongly increased when absorption surface is covered with selective coating characterized by high values of the ratio α_c / ε_c , where α_c, ε_c are coefficients of absorption and emissivity correspondingly,. By changing the values of α_c / ε_c of solar collector from 1 to 12 the efficiency of solar collector is increased from 45 to 60%. Typical values of η_0 and K_c for different designs of solar collectors are brought in Table A1 [24].

Table A1. Typical values of η_0 and K_c for different designs of solar collectors

The type of solar collector	η_0	K_c
Flat plate collector without glazing and without selective coating	0.95	15
Flat plate collector with glazing and without selective coating	0.85	7
Flat plate collector with two glazing and without selective coating	0.75	5
Flat plate collector with glazing and with selective coating	0.8	3.5
Evacuated glass tubes solar collector	0.75	2

ATTACHMENT 2

THE CHARACTERISTICS OF SOLAR PHOTOVOLTAIC CELLS AND THEIR MEASUREMENTS

Solar photovoltaic cells can be used as any other source of direct current. They provide direct current of definite value at a given voltage, but contrary to conventional energy supply sources, output characteristics of solar photovoltaic cells depend on solar irradiance. Solar photovoltaic cells are non-linear devices and can't be characterized by simple equation.

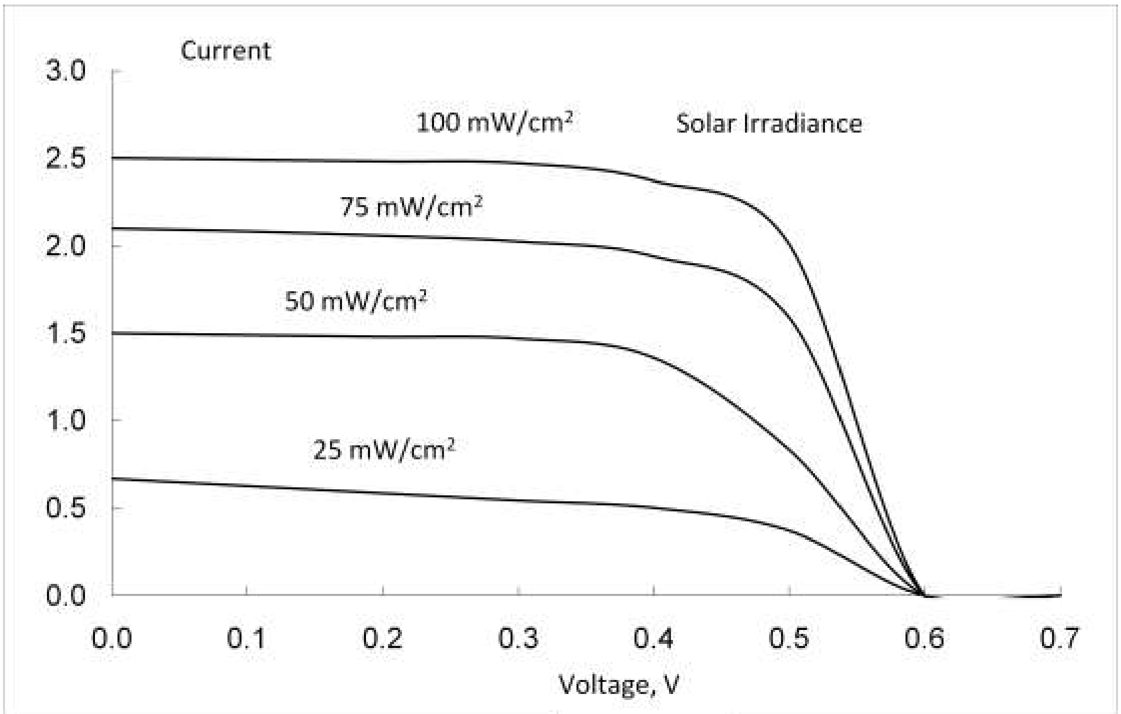

Fig. A.1. Current-Voltage curves (I-V curves) for solar photovoltaic cell at different values of solar irradiation (in mW/cm^2)

Series of curves of dependence of voltage and current on load for crystalline silicon solar cell at different values of solar irradiation in a simplified way are brought in Fig. A.1 [37]. $100mW/cm^2$ (or $1000W/m^2$) relates to solar irradiation on the horizontal surface at the sea level at noon under clear sky conditions. I-V characteristics of solar photovoltaic cells are investigated in accordance with principal scheme of measurements brought in Fig. A.2.

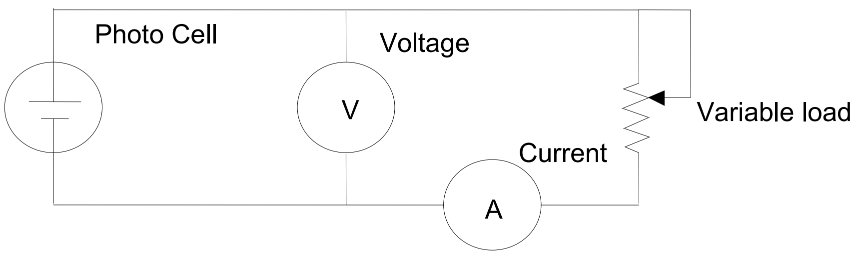

Fig. A.2. The electrical scheme of measurements of voltage and current of solar photovoltaic cell.

Output voltage V of solar cell and current I through the load are measured by changing the ohmic load resistance (high-precision variable resistor/potentiometer). The light intensity is maintained constant during the measurements. First, the resistance of load is brought to maximum value by potentiometer, so there is, practically, no current in the circuit and the output voltage V is equal to open circuit voltage V_{oc} which is by definition the voltage produced by solar cell when no load is applied (around 0.6V). Then, as the resistance of load is gradually reduced by potentiometer, direct current emerges in the circuit and increases up to some definite value, and, at the same time, the voltage decreases. Subsequent drop of resistance up to short circuit practically doesn't cause subsequent increase of output current. This maximum value of current is denoted as short circuit current I_{sc} (see Fig. A1, A3). I-V curves are brought in Fig. A.1 in simplified form. In reality, open circuit voltage V_{oc} decreases within small range as the intensity of solar radiation decreases. The output power of solar cell P_{out} is the product of the measured

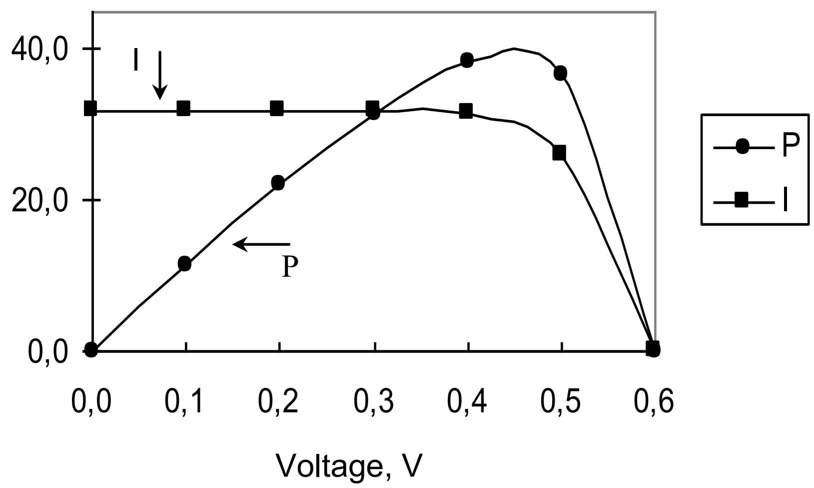

Fig. A.3. Typical I-V and P-V curves of solar cell

voltage and current ($P_{out} = I \times V$). The curve of output power P of solar cell depending on voltage V is presented in Fig. A.3. For I-V curve that is also brought in Fig. A.3 in its left part the current has maximum value $I = I_{sc}$ at V = O, but the output power ($I \times V$) is equal to zero, and in the right part of Fig. A.1 I = 0 at maximum value of $V = V_{oc}$ and the output power is also equal to zero. Maximum power corresponds to the voltage of around 0.45V. The maximum power is reached at around 0.45V regardless of light intensity.

Described method of I-V characteristics measurements allows to compare different solar cells under equal conditions, as well as to evaluate the quality of solar cells. By using instead of potentiometer simple electronic control device based on operative amplifier (micro scheme) essentially the precision of and rate of measurements is increased. With that these devices can be constructed at home conditions [37]. To compare characteristics of different solar cells their measurements are done under standard conditions. The temperature of solar cells during the measurements is 25^0C. Under solar radiation in a while the temperature of solar cells can rise up to 50^0C. In this case some drop of open circuit voltage V_{oc} and output power P_{out} and small rise of short circuit current I_{sc} are registered.

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ATTACHMENT 3.

APPLICATIONS OF RENEWABLE ENERGY SOURCES

Solar cooker near t. Abovyan (2010)

Large-scale solar dryer (SHEN NGO)

Solar Parabolic Trough Collector installed at the roof of SEUA

Powerhouse of Benzar small HPP at Zor-zor river near t. Sisian

PV systems to provide seismic observation stations with electricity

Solar water heaters installed on the roof of school in t. Ararat (2009)

Solar water heaters at Hotel Erebuni

Solar water heaters installed in Jrvezh, Armenia

Bathroom operated through solar water heating

Solar dryers developed in Vanadzor (2010)

Nubarashen Landfill Gas Capture Project

Landfill gas collection and firing at Nubarashen landfill (poto courtesy Climate Change Center)

Gas collection wells and pipes at Nubarashen Landfill (poto courtesy Climate Change Center)

Solar photovoltaic panels at the roof of Surb Sargis church in Yerevan

Biogas production set at Agroservice 1

Solar photovoltaic panels at the roof of SEUA

In 1984, a unique solar furnace with 10m diameter parabolic concentrator with vertical optical axis, $120m^2$ surface area, sun tracking heliostat and 1.2 kW off-grid PV station have been commissioned. The installation had been designed for material science needs and, in addition, had a cylindrical thermo-PV receiver placed in the focus of the parabolic mirror concentrator.