Conference paper

Utilisation of solar energy+

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The main aim of the paper is to present the overview of solar energy technologies and possibilities of applying them in Poland. In this paper the main stress is put on photothermal energy conversion, photovoltaic conversion is only mentioned. The emphasis is focus on identification the problem when and how the solar energy can be used in our country. The main characteristic data of Polish climate are presented and analysed. Solar radiation is considered more carefully. Some detailed information about distribution, structure and availability of solar radiation are given. The changes of availability of global solar irradiance and its components (direct, diffuse, reflective) that incident upon surfaces with different inclination angles are presented. Cold climate, nature of distribution of solar radiation, its non-regular duration and specific structure determine the solutions to problems and give some indications to the construction of solar systems in Poland. Some remarks according passive systems in Polish climatic conditions are also given. The most effective applications of solar energy for Polish conditions are classified and described.

1. Introduction

There are three main forms of renewable energies [1]. They are more or less connected with solar energy. We can consider following categories:

• direct forms of solar energy;

• indirect forms of solar energy – secondary effects of solar radiation;

• other sources of renewable energy.

Direct use of solar radiation has always been applied by mankind for light and fire. Actually, when we consider planned utilisation of solar energy [2], we usually divide it into:

• decentralised methods of utilisation of solar energy and its photo-thermal conversion in low temperature systems, i.e.:

– active solar heating systems with flat plate solar collectors, so called solar space and water heating;

– passive solar heating systems – solar architecture.

• decentralised methods of utilisation of solar energy and its photo-electric conversion in photovoltaics systems.

• decentralised methods of utilisation of solar energy and its electric and thermal conversion in thermal-electric power stations equipped with parabolic trough concentrators, so called solar-thermal electricity generation;

• centralised methods of utilisation of solar energy and its thermal and electric conversion in solar dish and solar power tower stations.

Most of the forms of energy conversion from the second group, mentioned above, have been already used by people for thousands of years. In this group [3] we have as follows:

• hydro energy;

• wind energy,

• biomass energy (waste heat can be included, when it consists biological components);

• wave energy;

• environmental heat (used by heat pumps).

To other forms of energy we can include:

• geothermal energy,

• tidial energy.

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2. Variety of solar technologies

Considering different application of solar energy we can start our review from decentralised methods of utilisation of solar energy and its photo-thermal conversion in low temperature systems, i.e. active and passive solar systems.

We can define active solar heating systems as installations in which solar energy is converted into heat in special technological devices as solar collectors, that can operate due to additional auxiliary energy (to drive circulating pumps or vans). Solar collectors are used to absorb and collect solar radiation and transfer it into circulating fluid. Heat is transferred by means of this fluid to the storage medium in a storage tank, then is used in controlled way according to heat demand.

In passive systems solar radiation is used in natural way for heating or cooling purposes by appropriate construction and orientation of buildings, without further technical measures. No additional, auxiliary energy is needed to drive the system, i.e. to make heat transfer fluid circulate between solar energy absorber and user of the heat. Air is usually used as a heat transfer medium in passive systems. When its movement is forced by means of vans, than we consider a semi-passive system.

PV – PhotoVoltaics is technology of converting light to electricity in direct way. This technology is not analysed in this paper, because the main subject is: thermal conversion of solar energy. However, PV must be mentioned when the general review of solar technologies is presented.

Next, decentralised and centralised methods of solar -thermal electricity generation are considered . Electricity is produced by a solar-thermal generator driven by steam turbine. The temperature of above 350°C must be reached. It can be done only by using systems, that concentrate the sunlight. Depending on different optical principles, concentration process can be achieved by applying:

• parabolic trough concentrators, that are used in solar farms;

• a great number of heliostats – solar tracking mirrors, that concentrate sunlight on a central receiver mounted at the top of solar power tower;

• parabolic concave mirrors, that concentrate sunlight on a receiver mounted at the focus – parabolic dish system.

It must be stressed, that all solar systems that are based on concentration effect utilise only direct solar radiation. Different situation exists in case of solar systems equipped with flat plate solar collectors, that absorb direct, diffuse and reflect radiation, the last component occurs in case of tilted surfaces.

3. Availability of solar energy depending on climatic conditions and other parameters

In general, the main factors that create the climate in a given region, are:

• solar radiation (value of heat flux, direction of incident radiation, amount of sunshine hours);

• temperature of ambient air;

• wind (velocity, direction);

• rainfall and air humidity;

• sky clearness index.

The ambient temperature is mainly determined by total sum of solar radiation, angle of incident radiation and total sunshine hours. The existence of big area of free water surface (sea, lake, pond) influences also on temperature level. Dry land area absorbs about two times more of solar energy in comparison with free water surface, that reflects a lot of the sunshine. The existence of greater water amount causes the decrease of ambient temperature due to applying the part of absorbed solar radiation energy to evaporation. However, during time without any insolation, dry land loses heat much quicker. Therefore daily and yearly temperature fluctuation in dry lands (Continental climate) are higher.

The ambient temperature is also dependent upon winds. The differences in amount of incident and absorbed solar radiation energy in different geographic latitudes cause the movement of air, i.e. winds. Disturbances of wind directions are caused by viscosity, gravitation and Coriolis strengths. All these factors influence on ambient temperature and give an impact in creating regional climatic conditions.

Rainfalls are connected with cloud formation. Cloud formation influences also on amount and structure of solar radiation incident upon earth surface. High pollution and dust particles in air can significally reduce the level of insolation in given region.

Climate is the most important factor that determines the possibilities of applying solar energy and methods of energy conversion. Particularly the following parameters are dominant:

• insolation level, i.e. the amount of solar heat flux, that incidents on horizontal or tilted surfaces;

• duration of solar radiation, so called solar hours;

• structure of solar radiation (fraction of diffuse, direct and reflect radiation, the last one in case of tilted surfaces)

• distribution of solar radiation.

Although pollution is not a parameter that characterised climate, but unfortunately it becomes more and more important factor, that influences on availability of solar radiation.

After this rather general consideration some detailed information about Polish climate can be presented and according to them indications to useful methods of energy conversion can be given.

3.1 Climatic conditions and availability of solar energy in Poland

Poland is located between 49–54,5° N latitudes in a moderate climate zone with influence of Atlantic and Continental climate. This location causes that Poland is affected by different atmospheric fronts, that cause frequently rainfall and heavy cloud formation. That is particularly evident in winter, autumn and early spring. North, at the sea side and in the west part of Poland climate is more moderate. In winter in central Poland and especially in the east part due to influence of Continental fronts, climate is heavy, with low ambient temperature and relatively high daily temperature fluctuations. In Warsaw averaged yearly the mean daily amplitude is equal to 8.5°C [4]. For east Polish regions daily temperature fluctuations are especially high and this amplitude is greater than 10°C. The mean monthly ambient air temperatures (averaged over 30 years period) for Warsaw are given in Table 1 [5]. This table contains also the other climatic data for Warsaw, like mean monthly wind velocity, mean monthly rainfalls and mean monthly sum of solar radiation incident upon horizontal surface with remarks on percentage of diffuse radiation [6].

An average annual insolation on horizontal plane is in range 950 – 1150 kWh/m^2. In the north part of Poland the annual average insolation has the highest level. Warsaw is situated in central Poland, the total annual solar heat flux density accounts there for 962 kWh/m^2. The maximal solar radiation occurs in June and it is in average equal to 160 kWh/m^2. During the warmer half of a year, from April to the end of September there is about three times more of solar energy than in the colder half year period. From October to April only about 20% of annual total radiation is available. The minimum insolation occurs in December and for Warsaw is equal to about 11 kWh/m^2. It is evident, that system which operates seasonally, in spring and summer, are preferable in Polish conditions.

The structure of solar radiation is characterised by a very high share of a diffuse radiation. An average annual percentage of direct radiation amounts only for 46%. In summer of course there is more direct radiation about 56%. However, from November to the end of February the percentage of diffuse radiation varies from 65 to 71%. This situation recommends solar systems that use both direct and diffuse solar radiation. Therefore, it must be said here, that all systems, equipped with concentrators, that use only direct solar radiation, like solar-thermal-electric power station can not be recommended for Polish conditions.

Solar operation during the year is in average equal to 1600 hours, that is about 18% of the total annual period of time. The annual duration of solar operation [7] can vary for different Polish regions, the maximal difference is equal to 450 hours. In winter the average daily solar operation is equal to seven hours, but useful solar radiation energy level (useful for systems applying solar energy) occurs for short time, that in December is only about 3 hours per day. In June this time is the longest and can last even 15 hours. The annual solar operation time e.g. for Warsaw is the same as for example for Freiburg in Germany and a little shorter than in Paris. However, the total radiation level in Freiburg is nearly 20 % higher and in Paris about 16% higher then in Poland.

Table 1 gives the mean monthly values of solar heat flux on horizontal surface for Warsaw. Table 2 repeats this data in order to make more clear the differences in solar radiation incident on surfaces with different inclination angle. Table 2 contains also more detailed data, i.e. values of direct, diffuse ir-

Table 1. The averaged climatic conditions in Warsaw. The mean monthly ambient air temperature, wind velocity, rainfalls, solar radiation on horizontal surface with percentage of diffuse radiation.

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Temp. [°C]	–3.5	–2.6	1.2	7.8	13.8	17.3	19.1	18.2	13.9	8.1	3.0	–0.6
Wind [m/s]	3.5	3.5	3.5	3.25	2.8	2.4	2.45	2.45	2.7	2.82	3.2	3.3
Rain [mm]	22.	18.	29.	28.	59.	82.	57.	60.	41.	26.	35.	36.
Insol. [MJ/m^2]	62.	102.	253.	357.	494.	577.	558.	475.	308.	161.	60.	41.
Diffuse [%]	66.	65.	53.	50.	47.	42.	44.	44.	46.	54.	67.	71.

radiance and in case of tilted surfaces also values of reflect irradiance.

In general, Polish climatic conditions are characterised by very high variation of solar energy level. That is characteristic for different time periods, for a short time period – a day, and a long time period - a year. In winter the insolation level is very low and duration of insolation is very short, ambient temperature is also quite low and consequently the heat demand of buildings is quite high. When energy is needed for space heating purposes the time and the peak values of heat demand are quite opposite time and peak values of available solar radiation. The periods for „solar energy supply“ and „solar energy demand“ are quite opposite. Due to heavy climatic conditions application of solar energy for space heating, without seasonal storage – from summer to winter time, is very limited.

3.2 Solar radiation on tilted surfaces

Analysing possible application of solar energy we usually do not consider the horizontal surfaces. The main components of active solar systems, solar collectors, photovoltaic modules, are tilted to horizontal ground surface. Solar energy applied in building structure in passive systems do not incident only on horizontal elements of building envelope. Most of the building walls and windows are vertical or tilted. The special elements of building structure that create some passive solution, like different sun glass spaces, buffer zones, atria, roofs are not also horizontal.

The influence of inclination angle of a given surface on amount of energy incident upon this surface has been analysed for Polish conditions [8]. The calculations have been made for different inclination angles of absorbing surfaces, that are situated in Warsaw. The results from the calculations for horizontal, tilted (at angle 45°) and vertical surfaces are presented in Table 2.

The analysis has been performed for global radiation and its components. Some remarks and conclusions are presented below.

In general, it can be said that the effect of the tilted surface under the angle, that is a little less than local latitude (for Warsaw 45°), results in more uniform distribution of solar heat flux over the warmer part of the year. From May till July monthly heat flux values are smaller and during the rest months higher in compare with horizontal surface. In some winter months solar radiation is even nearly two times higher but still very low (see Table 2). Total monthly energy incident on tilted surface is 10% higher than on horizontal and 28% more than on vertical. Such position of absorbing surface cause better use of direct radiation from August till April (in autumn and

Table 2. Mean monthly total, diffuse, direct and reflective irradiance for surfaces faced to the south and inclined to horizontal surface at different angles (i.e. 0° – horizontal, 45° – tilted, 90° – vertical) for Warsaw.

[MJ/m]												
Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Horizontal surface												
Total	62.	102.	253.	357.	494.	577.	557.	475.	308.	161.	60.	41.
Diffuse	41.	67.	134.	178.	235.	249.	250.	210.	141.	87.	40.	29.
Direct	21.	35.	119.	179.	259.	328.	307.	265.	167.	74.	20.	12.
Tilted – 45° surface												
Total	110.	150.	329.	388.	466.	530.	522.	496.	385.	235.	97.	77.
Diffuse	33.	65.	118.	160.	211.	210.	212.	177.	130.	61.	33.	26.
Direct	75.	82.	205.	220.	255.	305.	296.	306.	245.	164.	62.	50.
Reflect	2.	3.	6.	8.	12.	15.	14.	13.	10.	7.	2.	1.
Vertical surface												
Total	111.	142.	267.	275.	296.	306.	312.	328.	296.	213.	97.	79.
Diffuse	23.	31.	71.	85.	122.	133.	131.	114.	62.	46.	26.	21.
Direct	80.	95.	172.	148.	122.	110.	125.	161.	193.	151.	62.	54.
Reflect	8.	16.	24.	42.	52.	63.	56.	53.	41.	16.	9.	4.

winter), in the rest of the year it is opposite. The percentage of reflected radiation is very low and does not really influence on total value of absorbed solar energy (it varies in range from 1 to 4%).

Considering the vertical surface, it turns out that such position cause in warmer months from March till the end of September, and especially from May till end of August, significaly reduction in reception of solar radiation (see Table 2.). The highest reduction is in direct radiation, that for example in June is three times less than for horizontal surface (horizontal – 327 MJ/m^2, – vertical 110 MJ/m^2, see Table 2). When the surface becomes more vertical then the impact of reflect radiation increases. For example in June the percentage of reflect radiation accounts for nearly 20% of total radiation. Analysing winter months, regarding to data from Table 2, it is evident that values of total solar radiation incident on vertical and tilted surface (angle 45° to horizontal surface) are very similar. However, the percentage of different radiation components varies, as it was noticed, there is more reflect radiation for vertical surfaces.

The coefficient of reflection depends upon the kind of ground cover. If the reflection of the background is high and the main aim is to increase the amount of available solar energy in winter time, then the surface that absorbs solar radiation ought to be positioning more vertically. The calculation for tilted surfaces have been made with assumption that the coefficient of reflection is equal to 0.2.

Analysing different systems we must know, which component of the global irradiance is the most important for our application. Apart that, usually, in an active solar system, it is essential to maximise the solar gains. However, considering the passive systems the more carefully analysis is needed, that allows to compromise the need of big heat gains in winter with necessity of reducing solar energy influence in summer (e.g. in Poland). The last remarks is especially true for most time of the year in low latitudes country.

The specific nature of Polish climate, distribution and structure of solar radiation determine possible utilisation of solar energy and indicate some solutions of active solar systems and building construction. The solar systems must collect both radiation, diffuse and direct. Systems applying only direct radiation can not operate effectively in Polish climatic conditions. Systems that can operate seasonable, during warm, sunshine part of the year, would be very promoting alternative. The active systems with flat plate solar collectors can be used with good efficiency for many different application [9].

4. Efficient application of solar energy in Poland

The results show [10], that DHW – Domestic Hot Water systems are very effective during spring and summer, especially from June to the end of August. In average in that time they can provide about 90 – 100% of total demand. In other warmer months , i.e. in April, May, September and October these systems can meet the hot water energy requirements in 70 – 90%. Of course the size of the system depends upon the number of users. The calculations show that in Polish climatic conditions, taking into account a typical flat plate water collector, the required area of the collector is about 1 m^2 for one person (when system operates only in summer). Therefore typical small summer house, camping house require about 4 m^2 of flat plate solar collectors with storage tank about 300-400 litters capacity. Very good efficiency of DHW system in summer time is very promoting for summer resorts.

Due to the low temperature of heating medium flat plate solar collectors are adequate for solar energy reception, even without selective absorber surface, and sometimes without plastic cover. However, it has to be mentioned that a solar DHW system from November till the end of February is ineffective, providing only about 5-10% of total hot water energy requirements. The increase of solar collectors area does not effect on the total solar thermal performance of the system. Therefore even for the system that operates in whole year cycle, like DHW in single family house, the recommended area is about 1,5 m^2 for one person and it gives total yearly input of solar energy in range 60-70 % .

The use of solar energy in agriculture is also very promoting solution. In most of agriculture application the low temperature sources of energy are needed. The time and the peak values of solar energy, are very often in quite good accordance with the time and peak values of the heat demand, e.g. in some sectors of agriculture production, domestic hot water heating and solar drying. In Poland most part of agriculture production takes place between May and August, that period of time is also characterised by the best insolation conditions, with monthly average minimum value equal to 135 kWh/m^2. Especially the possibility of applying solar energy for drying purposes is very promoting alternative.

Polish climatic conditions can give also some suggestions to passive solar systems. The proper construction of the house, applying buffer zones, winter gardens, solar collecting surfaces and accumulating massive walls, can give a great positive impact to the total

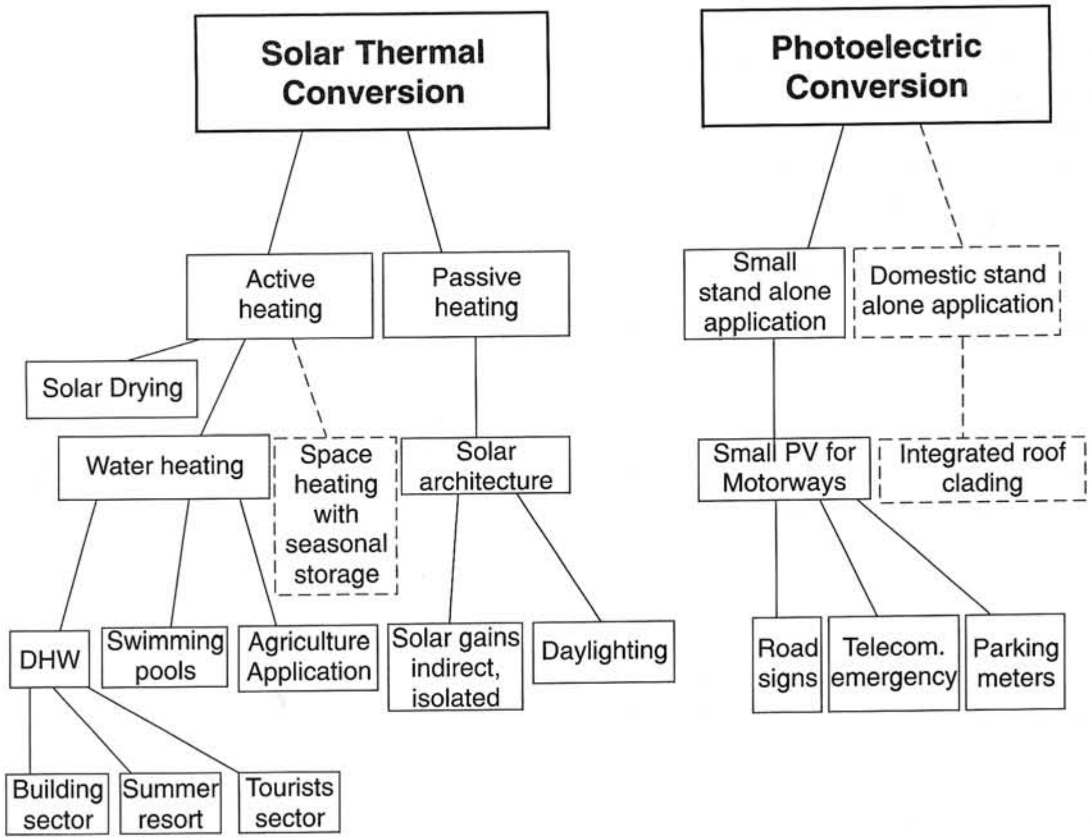

Fig. 1 Possible options for solar energy applications in Poland.

heat balance of the building. However, the passive systems must be considered very carefully. In Polish conditions, too many glass walls and solar collecting surfaces can give an unexpected effect in extremal weather conditions, i.e. too much heat gains in summer, too much heat losses in winter.

5. Prospects for solar energy in Poland. Conclusions

Figure 1 shows the main available options of solar technologies in Poland. In Polish conditions we can consider two main methods of energy conversion:

- photothermal, converting solar radiation into heat;
- photovoltaic, converting solar radiation into electricity.

Of course in frame of both of these two main solar technologies there are many others and many different application are possible. They are shown in Fig.1. These options are connected not only with very specific Polish climatic conditions, but also with some trends in Polish energy policy.

Consideration about solar thermal ought to be divided into two main methods, active and passive. Regarding solar thermal conversion in active systems and taking into account Polish climatic conditions it must be emphasised that the real potential for effective use of solar thermal energy is to apply flat plate liquid solar collectors for water heating for: domestic hot water systems, swimming pools and other low temperature application, or air collectors for drying purposes, especially for agriculture application. When the problems of long term (seasonal) solar energy storage can be solved then solar energy can be effectively used for space heating purposes. One of the most proper idea in Polish conditions is to store solar energy in ground medium. Energy conservation is then achieved through underground seasonal energy storage [11].

Heat demand in Poland is high not only due to strong climate, especially winter conditions, but mostly due to not proper building structure, materials, insulation, windows, lack of metering and control equipment and not proper billing system that do not make people think about energy conservation. It turns out that solar passive systems can improve significantly thermal building comfort. However, solar architecture must be adequate to our climatic conditions, not every typical passive solution is proper for Polish conditions (e.g. Trombe wall is not thermal effective system).

Strong coal energy lobby exists in Poland, therefore it is so difficult to introduce new fuel into market and especially to use solar energy to produce electricity.

Therefore it is expected, that in the near future only small stand alone photovoltaics application (i.e. parking meters, traffic signals, emergency phones) will be applied in our country.

Generally the main barriers to penetration of solar technologies in Poland can be classified according to these technologies in following way:

PV: electricity from coal, PV – low efficiency, very high costs, barriers on grid,

Active: few producers, relatively high capital cost, no retail outlets,

Passive: no education, no tradition, architects and planners reluctant to this design.

Concluded, regarding only thermal conversion of solar energy, it is presented, that the most profitable heating installations are that which operate mainly in summer time. DHW solar systems have very good thermal performance in summer time and even in longer period, if they are designed in a proper way. It is thought, that DHW solar system is a good designed when the yearly solar fraction accounts for 65% or more. Solar energy has been found also very attractive for agriculture application, mainly for hot water supplies, space heating in greenhouses and drying purposes. Solar collectors and elements of passive systems can be successfully placed within the already existing structure, without great modification, since till now typical village and small town settlement houses were very simple in shape, one-storey and with large area uncovered roofs.

When the first barriers connected with solar energy are overcome the most advanced technologies could be introduced.

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