Solar Energy Use for Thermal Application in Poland

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Abstract

The paper presents some aspects of solar radiation conditions in Poland and solar energy availability. Data for solar radiation on surfaces with different slope and orientation are important for elements of a building an envelope, as well as for solar collectors of active heating systems. Heating/cooling needs of a room depend strongly on room location, which is a result of solar energy impact. Solar energy can be used for passive heating in winter, spring and autumn, especially by the south facade. In summer, shading is necessary and problems of overheating because of too much solar gain are evident at attics. Solar energy also can be effectively used for active heating. Types and solutions of solar active heating systems are described. Prospects for solar system development are analyzed.

Keywords: solar energy availability, heating/cooling needs, solar heating systems, solar technology development

Introduction

Solar energy systems are the most environmentally friendly energy technologies. In Poland, utilization of solar energy is mainly connected with the building sector. However, up to now utilization of solar energy in buildings has not reached even a small share of energy use [1].

In Poland it is especially difficult to implement renewable energy technologies because of the strong coal energy lobby and the common opinion that these technologies, and especially solar energy technologies, are expensive and not efficient in our climatic conditions. Therefore, to introduce solar energy technologies it is necessary to promote them as modern options for energy conservation in buildings that should be implemented when energy-efficient measures have already been applied. Thus both options can reduce total energy consumption significantly and, in consequence, reduce environmental pollution.

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Implementation of solar energy technologies in buildings calls for interdisciplinary attempts to solve energy problems. It is necessary to consider energy extraction (collection), conversion, storage and use in a coherent way. The following problems should be analyzed:

- availability of solar radiation;
- creation/design of a building envelope with regard to solar irradiation to increase or reduce solar energy impact depending on the season;
- implementation of solar passive technologies, with focus on thermal conversion of solar energy in a building envelope and energy storage in building elements suitable for the season and local conditions;
- implementation of solar active systems, including stand-alone and roof-integrated solar collectors, PV modules and photovoltaic facades;
- maximizing solar energy use in solar active systems;
- assuring short- and long-term solar energy storage;
- analysis of application of solar hybrid heating systems: combined solar with gas boiler(s); combined solar and biomass boiler or chimney heating systems; combined solar with heat pumps.

Architecture of a building is a crucial point of thermal energy balance of the building and indoor living comfort. It is important how to design a building envelope to meet seasonally varying energy needs. In Poland, as in other high-latitude countries, winter heat demand for space heating is high and a building envelope should receive maximum incident solar energy. On the other hand, in summer walls and roofs exposed to incident solar radiation usually require shading rather than too much solar gain. It is important to try to meet these two opposite requirements. In addition, if a building is equipped with an active solar system it is necessary to maximize solar energy use throughout the year. To design solar energy-efficient buildings it is necessary to take into account both active and passive solar energy use, and protection against too much solar energy gains. The base for that is to know the solar energy availability.

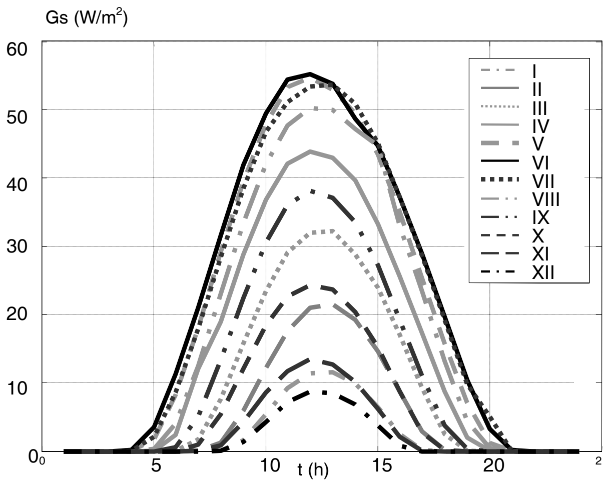

Fig. 1. Distribution of solar irradiance during averaged days for every month of a year for horizontal surfaces in Warszawa.

Solar Energy Availability

Solar energy irradiation, its distribution in time and availability for different locations are crucial for determining solar technologies suitable for given applications. In Poland the average annual irradiation on a horizontal plane is in the range 950-1,150 kWh/m^2 [2]. In the northern part of Poland annual average irradiation is at the highest level. The highest solar irradiation occurs in June, where in Warszawa the average monthly irradiation is equal to 160 kWh/m^2. The lowest solar irradiation occurs in December and the averaged monthly irradiation is equal to 11 kWh/m^2. In October-March only 20% of annual total radiation is available. The structure of solar radiation is characterized by a very high share of diffuse radiation. An average annual percentage of direct radiation amounts to 46%. In summer the share of direct radiation is higher and accounts for 56%. In November-January diffuse radiation varies from 65 to 71% [2].

Fig. 1 presents total solar irradiance on a horizontal surface based on the averaged representative hourly solar radiation model for Warszawa (the model is based on the 30-year period of measurement series of hourly total and diffuse radiation for an actinometrical station in Warszawa-Bielany and is presented in literature [3]).

Solar irradiance data presented in Fig. 1 have been used as input data for calculations of solar radiation incident on surfaces with different azimuth (orientation) and inclination angles. The calculations of solar radiation incident on surfaces with different azimuth and inclination angles have been performed using the anisotropic sky model, Hay-Davies-Klucher-Reindl (HDKR) [4]. Considering the use of solar energy, the focus is put on surfaces inclined with different orientation that constitute the elements of solar systems especially designed to collect solar energy, as well as building envelope surfaces.

Fig. 2 shows the distribution of solar irradiance during averaged days for every month of the year for vertical south (A) and north (B) surfaces. There is a high difference in

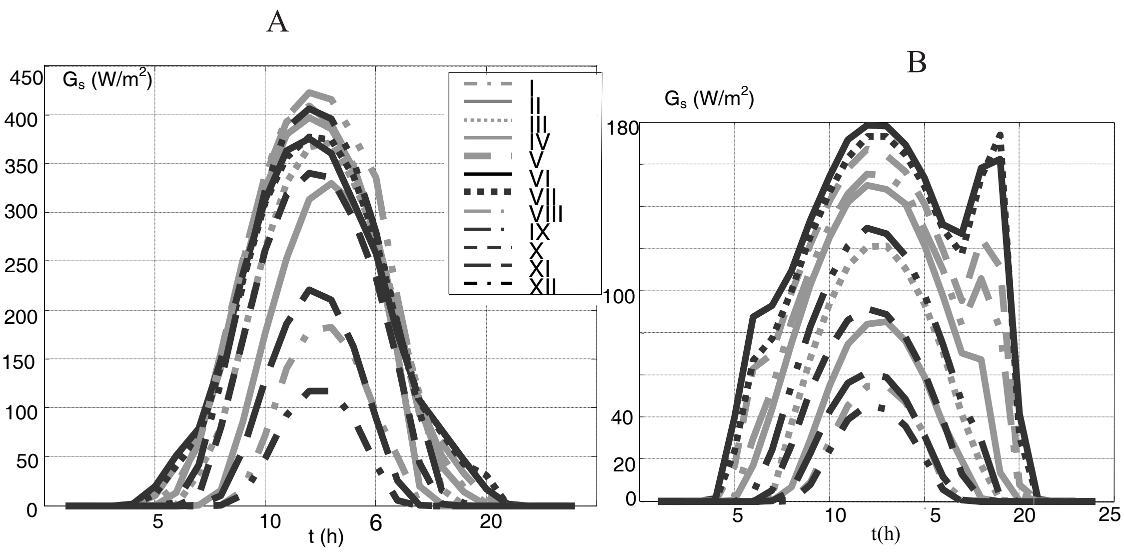

Fig. 2. Distribution of solar irradiance during averaged days for every month of the year for vertical south (A) and north (B) surfaces (in different scales) [6].

Table 1. Annual energy demand for heating and cooling for selected cases of rooms with different locations and window sizes [5].

Window Size [m^2]	β [º] slope	γ [º] azimuth	Qc [MJ] Cooling demand	Q_h [MJ] Heating demand	Q_{tot} [MJ] Annual energy demand	Q_h/Q_{tot} [%]
1x1	90	0	700.7	1,449.7	2,150.4	0.67
1x1	90	-90	517.4	1,851.3	2,368.7	0.78
1x1	90	+90	695.9	1,754.6	2,450.6	0.72
1x1	90	180	255.4	2,048.0	2,303.3	0.89
2x2	90	0	**4,078.08**	1,884.19	5,962.27	0.32
2x2	90	-90	2,791.18	2,969.04	5,760.22	0.52
2x2	90	90	3,729.28	2,802.82	6,532.10	0.43
2x2	90	180	1,568.00	**3,573.52**	5,141.52	0.70
1x1	45	0	1,252.34	1,430.07	2,682.41	0.53
1x1	45	-90	844.40	1,772.44	2,616.84	0.68
1x1	45	90	1,038.21	1,671.72	2,709.93	0.62
1x1	45	180	551.39	2,070.42	2,621.81	0.79
2x2	45	0	**6,481.75**	2,008.76	**8,490.51**	0.24
2x2	45	-90	**4,503.87**	**3,019.36**	**7,523.23**	0.40
2x2	45	90	**5,326.95**	2,681.28	**8,008.23**	0.33
2x2	45	180	2,790.87	**3,642.97**	**6,433.84**	0.57

daily and monthly distribution of irradiation for these two surfaces and horizontal ones [5]. It is evident that in summer irradiation of vertical south surfaces (e.g. the south facade of a building) (Fig. 2 A) is much reduced compared to horizontal ones (e.g. horizontal flat roof or horizontal flat atrium surface) (Fig. 1). The overheating of spaces located directly under horizontal roofs can often be noticed in summer. This can also be a problem of spaces in attics [5]. In winter solar radiation irradiance on the south vertical wall is nearly two times higher than on horizontal and nearly three times higher than on north verticals. In a natural way the construction of a building, especially the south vertical facade, is suitable for solar radiation when it is needed and to reduce irradiation when necessary (in summer).

Analyzing Fig. 2, it can be seen that irradiation of north surfaces is much smaller, but even for such an inconvenient position of the surface with regard to the sun, the impact of solar energy is evident. The north vertical surface in summer can see the sun directly in the morning, but at that time solar irradiance is not high, and in the afternoon when the irradiance is relatively high, what is evident is a peak of distribution of solar irradiance curves. In winter solar irradiance is small.

Heating/Cooling Needs of a Room Depending on its Location in the Building

Any building is exposed to incident solar energy. Depending on its location, architecture, construction and materials, the impact of solar energy can be different [6-10]. To describe and solve the problem of dynamics of processes in a building envelope and surroundings a mathematical model of energy transfer phenomena in opaque and transparent elements has been developed. Focus has been put on the influence of solar energy and, because of that, special attention has been given to energy transfer through windows [5, 11]. A special quasi three-dimensional heat transfer model of the window edges and frame, a simplified one-dimensional model of the central part of glazing and one-dimensional model of the opaque wall have been developed. They have included unsteady heat conduction in the window edges, window frame and walls, and fully detailed equations to describe the radiation exchange between the ground, the sky and windows, solar radiation absorption, transmission or reflection on all surfaces, and the effects of orientation and inclination on them. The developed model allows many cases to be evaluated in a given time and allows broad conclusions to be drawn. For simulation of a developed mathematical model, the Matlab as programming language has been used (the elementary balances method has been used). The developed model takes into account the variations in time of ambient temperature and solar irradiation. Properties (thermal, optical) of construction materials (transparent and opaque) as well as actual component dimensions and location are assumed to be constant for simulation of the annual operation of the building and its energy systems. It is assumed that heating and cooling needs are supplied by the HVAC system with the heat recuperation that operates in a controlled way to assure the room air temperature to be constant in time all year.

The results of considered cases for a full year can be presented in a range of graphical forms showing how the energy demand changes by month, by hour, and by contributory factor as required [5, 11]. Results of energy demand changes for different window sizes, orientations and inclinations, show the influence of solar energy on energy balance of considered room cases. The selected results of simulation studies of some specific location of modeled rooms are presented in Table 1 [5]. In the first eight rows annual energy demands for heating and cooling are presented, for regular rooms (vertical walls) with small (first four rows) and big (next four rows) windows, and for attic rooms, accordingly with the same size of windows (small and big). The presented results are for specific building construction (good insulation, high thermal capacity in consequence, low thermal losses through the opaque envelope), size and location of rooms. However, they give a clear picture of energy building needs in Central European (high latitude) countries.

The changes in heating/cooling demand presented in Table 1 result from the influence of solar energy and ambient temperature. The dominant factor is energy flow through windows, i.e. heat flow dependent on the temperature difference (ambient-indoor) and thermal quality of a window, and solar energy flow dependent on optical parameters of a window. Differences in energy demands caused by the different impacts of solar energy on energy balance of rooms are very clear in specific cases of window size, orientation and inclination. It is evident that overheating in summer due to high irradiation could be a real problem for some buildings' shapes and constructions, i.e. what is very evident for rooms at attics (β slope = 45º). In rooms under consideration, insulation of attic roofs is very good. If the thermal parameters of opaque elements are good, then windows and ventilation decide on energy balance of a building. To avoid overheating it is necessary to introduce shading envelope elements (which is not so easy for roof windows), shading devices (e.g. blinds, but external, however they are more expensive than internal) or to use cooling (air-conditioning) systems (not recommended because of high primary energy use). It can be stated that the best solution is not to use attics as living spaces.

It can be concluded that solar energy influence on energy balance of a building is evident, even in high latitude countries. Nowadays, when opaque envelope elements are characterized by high thermal insulation factors, heat transfer through them is much reduced and has the minor part of the energy balance. Windows are the crucial elements. It gives the opportunity to use solar energy through passive heating in winter, spring and autumn to reduce conventional heating energy loads supplied usually by a system based on fossil fuels. However, it is noticeable that problems of overheating in summer because of too much solar gain (especially at attics) can occur. It is recommended to "open" buildings to the sun to make them utilize solar energy when it is needed and "close" them to protect from negative influence when necessary. Passive solar systems should be introduced on the south part of the building, the north walls should be very well insulated, and the number and size of windows should be minimized at that side.

Solar Active Systems

Solar thermal systems are based on photothermal conversion of solar radiation into useful heat [12, 13]. In Poland, solar active systems are mostly used in the form of low temperature heating systems with flat plate or vacuum solar collectors, in which flow is forced by a mechanical device (a pump in a liquid system or a fan in an air system). Only in gravity (thermosyphon) systems are no mechanical elements used. However, such systems, because of climatic conditions, are not popular (low energy efficiency) in the country.

The nature of solar radiation and its periodical availability necessitates its storage. In a typical solar active heating system, storage has a short-term character, i.e. it is assumed to be sufficient for one to two days of hot water supply [14]. (However, in high latitude countries like Poland, a solar system must always be equipped with an auxiliary heater.) The useful energy of solar collectors is transferred by working fluid to a water storage tank. The stored energy is used when heat is required. When the useful solar energy cannot meet heating requirements the auxiliary heater is turn on. (In more reliable solar system with higher temperature requirements, the technology required is more modern and sophisticated, and the construction of the solar collector and the whole system, together with the control units, are more complicated.)

In Polish conditions, active systems with flat plate solar collectors can be used with good efficiency for many different applications [15]. The results show that domestic hot water systems are effective during spring and summer, especially from May to the end of August. In average in that time they can provide about 80-100% of total demand. It is recommended for DHW in single family houses to use 1.5 m^2 of flat plate solar collectors per person or 1 m^2 of vacuum tube solar collectors. In multifamily apartment buildings it is more efficient to use a smaller area of solar collectors for one person, i.e. 1 m^2 of flat plate solar collectors or 0.5 m^2 of vacuum tube solar collectors. Nowadays small-scale solar DHW systems are characterized by an annual share of solar energy in the range of 50-70% that gives an energy output of 500-650 kWh per kW_{th} of installed capacity. If solar combi systems (space heating and DHW) are used, then the collector area should be bigger, approximately by 30%, and the annual share of solar energy in heating energy can be in the range 20-30% and it is about 450-550 kWh of heating energy per kW_{th} of installed capacity [16].

Nowadays, about 3,000 PJ of heat is used for heating purposes in the country, less than 8 PJ is produced by solar active heating systems. Table 2 presents the present state and forecast for 2020 and 2030 of utilization of solar active heating systems in the country, if the solar energy promotion scenario is to be realized [17].

Economic efficiency expressed by the payback time of active solar heating system investment differs depending on the solar system producer and the fuel/heat source that is substituted, and can range from 6 to 16 years.

Table 2. Present state and forecast for solar thermal systems use [17].

Solar thermal energy use				
Year	Installed capacity [GW]	Area of solar collectors [10^6 m^2]	Area per person [m^2/person]	Annual energy [PJ]
2006	5.6	8	0.1	8
2020	112	160	2	160
2030	224	320	4	320

Prospects for Solar Systems

There is huge potential for solar heat application in the building sector. One of the most important barriers to the development of the solar thermal market has become the limitation of solar energy thermal systems only for domestic hot water. Nowadays, usually solar domestic hot water (DHW) systems constitute stand-alone heating systems. However, a new trend in energy management is for the integration of DHW and space heating. Solar systems can be used not only for domestic hot water but for space heating as well, especially since nowadays floor or wall heating systems operate at temperatures even lower than that required for hot water by the DHW system. Therefore, the new technology of combined solar systems, so-called combi systems (domestic hot water + space heating), should be promoted and implemented more quickly.

Solar thermal technologies are one of the major renewable technologies for the low-temperature heat supply. The key issue for the future is energy storage. To reduce storage capacity it is necessary to develop and foster fundamental and applied research in this area. Materials, especially phase change materials (PCMs), are crucial for storage technologies [18]. PCMs are chemical substances that undergo a solid-liquid transition at temperatures within the desired range for heating or cooling purposes. PCMs are characterised by an ability to hold greatly varying amounts of energy at the same temperature. PCMs can be used generally for both active and passive solar heating and cooling systems as well as in installations for domestic hot water preparation.

There is a need for research and development of advanced solar collectors, from the point of view of the working parameters, materials applied (optics), that give an increase in efficiency with the assurance of economic efficiency. In order to accelerate broad market deployment, the solar thermal industry should closely cooperate with other sectors such as construction, chemistry, materials, engineering (mostly cooling) and glass industry. It would be very good if Poland could develop solar thermal technology to assure high quality, reliable, long-lasting products to be implemented and integrated with buildings and to be spread all over Europe. This will be beneficial for the economy of the country and for reducing environmental pollution. It is always good to emphasize that solar energy uilization does not cause emissions any noise, and is an aesthetic solution for building architecture and construction.

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