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Section: Energy for Buildings

The effective use of renewable energy sources in office building

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Abstract

An increased utilization of renewable energy sources in the heat and electricity generation is one of priority tasks of the Slovak Republic to boost the use of domestic energy potential and thus to decrease the Slovakia's dependence on imported fossil fuels. Heat pumps and photovoltaics offer the most energy-efficient way to provide heating and cooling in many applications, as they can use renewable heat sources in our surroundings. The experimental workplace of our Faculty "Economic Research Centre for Renewable Energy Sources and Distribution systems" was founded with the purpose of investigating possibilities to reduce the energetic costs of buildings tied to economy. The realized project of the Centre creates real environment for effective implementation research of technologies in laboratory and operative conditions: technologies of co-generative elements, heat pumps, photovoltaics elements, thermal capillaries, and technologies in field of measurement and regulation. The result is the design with possibility to repeat it on other similar applications as well as the utilization of experience and determination of economical expedience of researched technologies implementation. In the contemporary phase of the research we evaluate of operative behavior of the zero-energy building, interaction with building constructions and study of inner climate parameters and overall results for central heat supply system.

Keywords: Renewable energy sources synergy; photovoltaic system; heat pump.

1. Introduction

The predetermination of selecting heating sources is becoming increasingly significant in an energy conscious world. Markets now offer many different types of heating sources, which need to be properly designed in order to achieve their required heating output. It is therefore necessary to take into account the possibilities of fuel consumption as well as heat transport. Since heating systems are dependent on regional weather conditions, proper consideration of all factors that influence energy output and efficiency could significantly reduce operating costs during the heating season. Currently, the greatest potential for energy savings to be achieved is in the design phase of the heating system. If renewable energy sources are considered, the environmental impact or carbon footprint can be substantially reduced compared to when only traditional energy sources are utilized.

In this article we deal with the issue of prediction and calculation of an amount of electricity using photovoltaic system. These calculated values are then compared to the values that were measured in real conditions. The calculated results are also compared with the results of another simulation program. After comparing all these collected values we will evaluate the computational model. On this basis, we continue to use a computational model to determine the amount of electricity produced for the administrative building in Košice. In the office building is installed renewable energy source in the form of heat pump based on water / water, which is devoted to the second part of the article. The result of such synergy between heat pump and photovoltaic system is to reduce the energy consumption of buildings on the zero energy level in the annual energy balance.

2. Research methods of renewable energy sources

2.1. Photovoltaic system

The existing photovoltaic system made of monocrystalline photovoltaic panels, from which measurements were taken, is located on a flat roof of an administrative building in Košice, Slovakia. Monocrystal photovoltaic panels have rated

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efficiency of solar energy transformation on the level around 20%. The system itself consists of 40 photovoltaic panels that are attached to two electric power converters. These converters are recording measurement values of the amount of produced electricity at 5-minute intervals. Photovoltaic panels (2x2x10pc.) are placed in rows on the flat roof of the building supported by a metal frame structure. The resulting DC power from the photovoltaic panels is transformed into DC voltage with 2 inverters for a single-phase AC voltage and an automatically phased inverter for a single phase AC voltage to two phases of a low voltage distribution grid. Each inverter is equipped with fuses, which automatically disconnect the photovoltaic solar generator from the distribution network when subjected to critical deviations of monitored parameters from the limits of standard values. The photovoltaic solar system is composed of 40 units of photovoltaic panels. The peak power of one photovoltaic panel is 230 Wp (Fig. 1).

Fig. 1. Installed photovoltaic system

The simulation program PVGIS was used to simulate the photovoltaic system. In order to quantify the amount of energy produced, a mathematical method was developed to calculate the amount of incident solar energy on the Earth's surface for any location and inclination of solar panels. The measured and simulated values of produced electric energy is set for comparison with the calculated values. This methodology for calculating the amount of electricity produced by the photovoltaic system partly used measured values for the city of Košice (cloud cover, ambient temperature, and direct sun glare).

2.2. Progressive indoor environmental system

Heating and cooling system incorporates a separate electricity meter. The electricity meter records consumption of electric energy source as well as circulation pumps in the building. Area includes heating source heat pump (HP), submersible pump (P1), and circulation pumps (P2-P5). Source cooling circuit includes a submersible pump (P1) and circulation pump source (P2 – P5) (Fig. 2). During the heating season is the biggest consumer of electricity in the system is heat pump. During the cooling period water from the source well is used for cooling, thus we are not producing cold in the building and in this case the heat pump is decommissioned (Fig. 2).

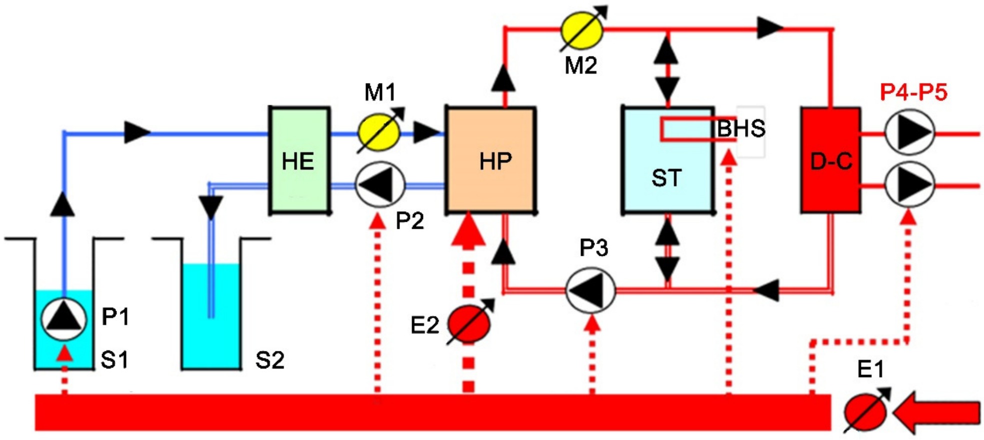

Fig. 2. Depicted scheme of the connection of a heat pump water/water

where:
- HE – heat exchanger;
- HP – heat pump water/water, 0°C/35°C COP 3,8; heat performance 95,3 kW;
- M1-2 – heat meter;
- E1-2 – electricity meter;
- ST – storage tank of heat;
- BHS - bivalent / backup heat;
- S1-2 – source / suction well;
- P1 – submersible pump;
- P2-3 – circulation pumps – engine room;
- P4-5 – circulation pumps – building;
- D-C – distributor-collector;

3. Calculation the amount of electricity produced by photovoltaic power system

This part of the article is dedicated to the calculation of produced electric energy. It is universal calculation model for the produced electricity that is applicable for the whole northern hemisphere of the planet Earth.

Fill factor (FF) is value that is often used to characterize the performance of the photovoltaic module (Eqn 1) [1].

$$FF = (V_{MPP} * I_{MPP}) / (V_{OC} * I_{SC}) \tag{1}$$

This factor is given as the ratio between the maximum performance point to the product curve of values of an open circuit voltage V_{OC} and short circuit current I_{SC}. This factor can also be portrayed as the ratio of two rectangles. From these rectangles we can determine the values of maximum voltage V_{MPP} and maximum electric current I_{MPP}. These values are added to the calculation based on characteristic values which are specified by the photovoltaic panel manufacturer [2].

An important relation involves a calculation of electric power at the maximum performance point P_{MPP} (Eqn 2) [3].

$$P_{MPP} = V_{MPP} * I_{MPP} \tag{2}$$

For our calculation the total active surface of photovoltaic collectors is considered A_{tot} (m^2). This value is used as a calculation input to determine total electricity P_{MPPtot} (Eqn 3) [3].

$$P_{MPPtot} = P_{MPP} * A_{tot} \tag{3}$$

If the nominal peak power or nominal power output of a photovoltaic system is known, it is unnecessary to know the conversion efficiency of solar energy, with the exception of calculating the area of the modules.

Nominal peak power is specified by the manufacturer of the module, or system and is calculated as the performance of a module subjected to 1000 W/m^2 of solar radiation (modular temperature is 25 °C and the Sun's spectrum corresponding to the quantity of air is 1,5). So for the photovoltaic modules to be 100% effective, 1 m^2 will need to obtain a peak output of 1 kW. These conditions are known as standard test conditions (STC).

Because in real conditions, modules are not 100 % effective, a larger space is required. If the module has an efficiency of 10%, then 10 m^2 is needed to produce a 1 kWp system. The effectiveness of the module for standard test conditions will be abbreviated as eff_{nom} (Eqn 4) [3].

$$eff_{nom} = P_{MPPtot} / (A_{tot} * 1000) \tag{4}$$

Nominal peak power P_{PK} is therefore the product of the area of modules A, and the effectiveness of the module for (STC) (Eqn 5) [3].

$$P_{PK} = A_{tot} * eff_{nom} \tag{5}$$

Actual performance depends on the radiation G and the actual efficiency of the photovoltaic module eff_{nom}, which is a function of irradiation and module temperature T_m. So to calculate actual performance P (Eqn 6) [3].

$$P = G/1000 * A * eff(G, T_m) = G/1000 * A * eff_{nom} * eff_{rel}(G, T_m) \tag{6}$$

The actual effectiveness of the module is a result of the nominal effectiveness eff_{nom} and the relative effectiveness of eff_{rel} (G, T_m) (Eqn 7).

By combining these two equations (Eqn 5) and (Eqn 6), we get the following equation [3].

$$P = G/1000 * P_{PK} * eff_{rel}(G, T_m) \tag{7}$$

Therefore, if the relative efficiency and peak power are known variables, it is not necessary to know the nominal efficiency, or active area of the photovoltaic module.

However, if either the nominal efficiency, or active area, is required, other two parameters will be required. If the nominal efficiency and peak power is known, we can calculate the active area using equation (Eqn 8) [3].

$$A = P_{PK} / eff_{nom} \tag{8}$$

So in fact, nominal efficiency is not used to calculate the amount of produced electricity. It is however useful for designing the size of photovoltaic system. The method used in this calculation to estimate the actual electricity generated from the chosen type of photovoltaic system is based on a mathematical formula that takes into account the first three of the above effects. This means that the method can be used only for photovoltaic technologies which do not depend primarily on the solar spectrum, and do not show adverse effects to long-term exposure to radiation, or high temperatures. Therefore, the computational procedure cannot be used to calculate the amount of electricity produced by modules made from amorphous silicon, which are more dependent on these two factors. The formula for estimating the relative efficiency is set out in the following equation (Eqn 9) [3].

$$eff_{rel}(G', T_m) = 1 + k1 * \ln(G') + k2 * \ln(G')^2 + k3 * T_m + k4 * T_m * \ln(G') + k5 * T_m * \ln(G')^2 + k6 * T_m{}^2 \tag{9}$$

In the formula enter the value of the G', which is calculated according to the following procedure (Eqn 10) [3].

$$G' = g/1000 \tag{10}$$

Coefficients k1 to k6 depend on the type of photovoltaic technology. These factors are expressed in the comparisons with measured values for each of the different technologies. The temperature of the module Tm is calculated from the ambient temperature according to the following formula (Eqn 11) [4].

$$T_m = T_{amb} + k_T * G \tag{11}$$

The following equation shows how the modules are heated by sunlight. This formula does not take into account the effects of cooling, such as wind or rain. If the photovoltaic system is in a very windy area, it will reduce the temperature of the modules, thereby increasing the efficiency of the photovoltaic modules. The k_T coefficient depends on the type of mounting for the photovoltaic system. In general, the structurally integrated system will be hotter than a freestanding system, because air can freely circulate around the back of the modules, cooling modules in the process. The following values were used in the calculation.

k_T = 0.035 °C / (W/m^2) for free standing systems [5]

k_T = 0.05 °C / (W/m^2) for building integrated systems [5]

4. Results of measured values

In the following part of this article we compare the measured values of electricity, the values calculated using the simulation program PVGIS and the values of electricity in calculation model, which are valid for the photovoltaic system that is installed at the administrative building in Košice, Slovakia.

The following chart processes measured results of the photovoltaic system encased in Košice (Fig. 3).

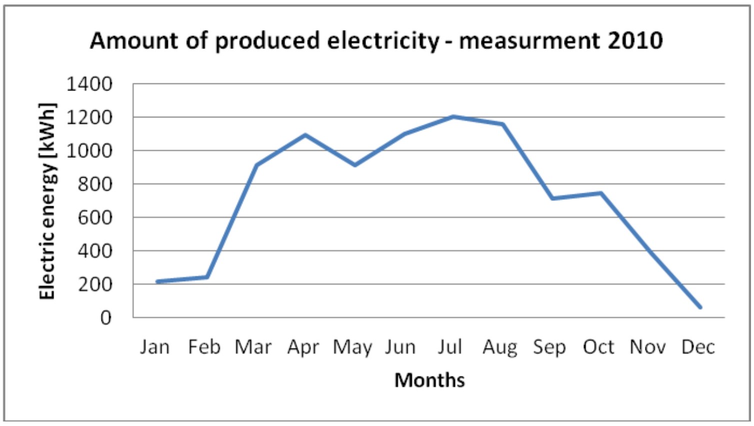

Fig. 3. Amount of electric energy produced – measurement

The graph below illustrates the amount of produced electricity, which is the result of a simulation of the installed photovoltaic system in the program PVGIS (Fig. 4).

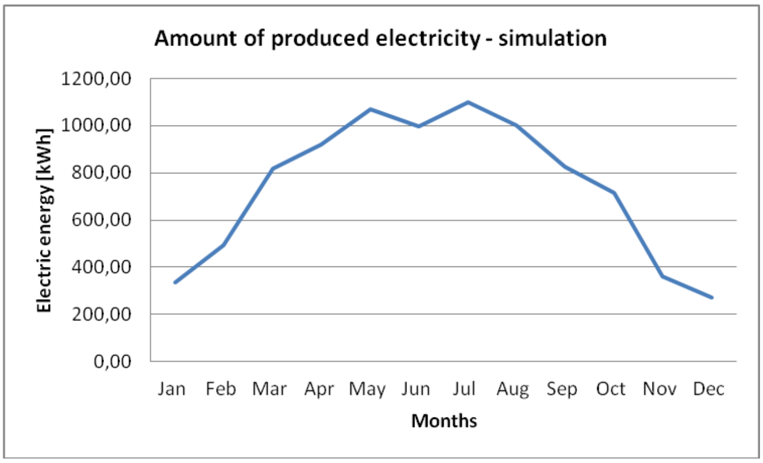

Fig. 4. Amount of produced electric energy – simulation

Calculation methods of generated electric energy are based on the methodology of calculating the amount of solar energy incident on the Earth's surface. The following chart depicts the curves of solar radiation incident on an inclined surface at an angle of 36° to the horizontal plane. The graph below shows the curve of electricity production based on calculated methods (Fig. 5) [3], [4].

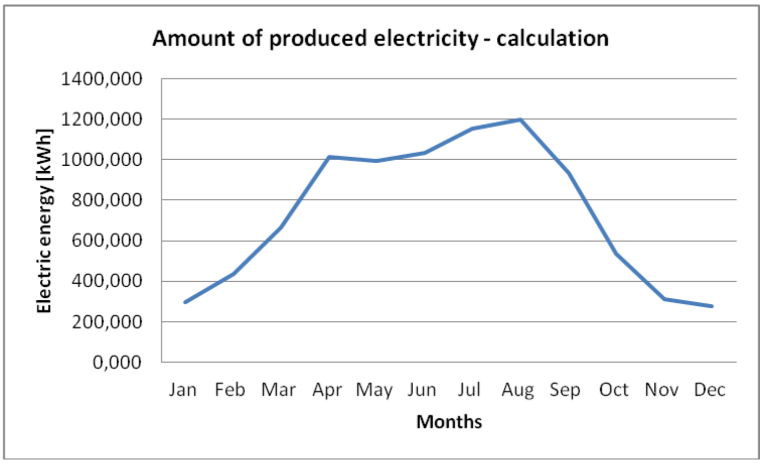

Fig. 5. Amount of produced electric energy – calculation

5. Produced electric energy comparison

When comparing the various curves of the produced electricity during the year, there are clear variations in the amount of energy produced each month (Fig. 6).

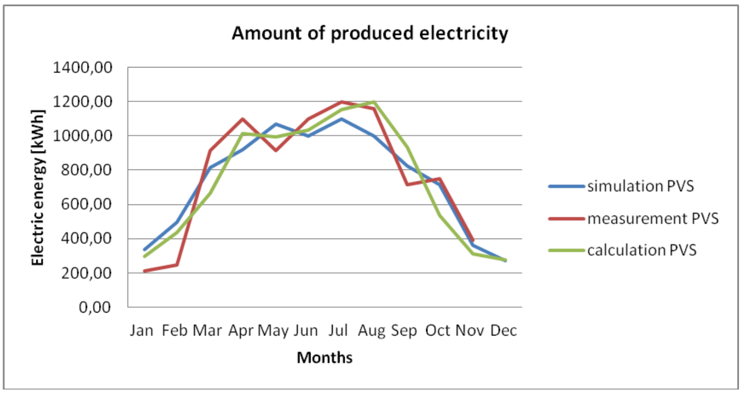

Fig. 6. Graphical comparison of resulting values

But when we look at the yearly sum of the measured values we obtain approximately identical results. These results are processed in the following table, where it is more favorable the methodology of calculating the amount of electricity produced for the selected location (Table 1).

Table 1. Comparison of measured data

Data collection methods	electric energy [kWh/year]	Variation [%]
Measurement	8752.505	–
Simulation	8920.000	1.88
Calculation	8840.974	1.00

6. Proposal of photovoltaic system at the evaluated administrative building

Photovoltaic panels will be placed in rows on the flat roof of the building in the metal framework structure. The resulting DC power from photovoltaic panels is transformed into DC voltage with inverters for single-phase AC voltage and automatically phased inverter for single phase AC voltage to two phases of low voltage distribution grid. Each inverter is equipped with security protection, which in case of deviations of monitored parameters from the limits of standard values automatically disconnects the photovoltaic solar generator from the distribution network. Photovoltaic solar system will be composed of 365 pieces of photovoltaic panels. The peak power of one photovoltaic panel will be 230 Wp. Depending on weather conditions for Slovakia, whole photovoltaic system is inclined at an angle of 35° [6] (Fig. 7).

Fig. 7. Proposal of photovoltaic system

7. Calculation of electricity produced by photovoltaic calculation model

After correctness confirmation of the electric energy production prediction by using the calculation model is the model used to simulate produced electricity with photovoltaic system at the administration building. The table below depicts the estimated quantity of electricity produced by the PV system on the basis of the defined configuration for, each month, angle and orientation of the PV modules. The table also shows the average value of daily and annual energy production.

The chart illustrates individual values that are the results of a simulation for a photovoltaic system at administrative building in Košice. HD is average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m^2) and HM is average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2). The values indicate the average daily ED and monthly EM electricity output of the photovoltaic system (Table 2).

Table 2. Produced electric energy by photovoltaic system

month	days	ED	EM	HD	HM
January	31	88.338	2738.478	1.1672	36.182
February	28	143.5524	4019.468	1.9846	55.57
March	31	198.3972	6150.312	3.3296	103.218
April	30	308.9588	9268.765	4.9795	149.384
May	31	291.8269	9046.633	4.6343	143.663
June	30	313.4476	9403.427	4.9368	148.103
July	31	338.421	10491.05	5.2899	163.988
August	31	353.2154	10949.68	5.4807	169.903
September	30	286.3894	8591.682	4.3878	131.633
October	31	160.152	4964.713	2.3931	74.188
November	30	96.2027	2886.08	1.3912	41.736
December	31	83.4367	2586.539	1.0837	33.594
Yearly average		221.8615	6758.069	3.4215	104.263
Total production		81096.825		1251.16	

8. Coverage of electricity during the year

Heating and cooling system incorporates a separate electricity meter. The electricity meter records consumption of electric energy source as well as circulation pumps in the building. Area includes heating source heat pump, submersible pump, circulation pumps. Source cooling circuit includes a submersible pump and circulation pump source (Table 3). If the user of the building decides to produce electricity using photovoltaic panels – can be also used so-called hybrid photovoltaic – thermal collectors, in which air is used to cool the photovoltaic panels used as supply air to the HVAC unit [7]. In this way, photovoltaic panel will provide preheated air while electricity will control central ventilation system with heat recovery using cross flow heat exchanger and heat pump [8].

Table 3. Consumption of electricity for heating and cooling during the year

Season	Produced heat/cold [kWh]	Consumed electricity source [kWh]	Consumed electricity circulation pumps [kWh]	Consumed electricity overall [kWh]
January	37881	9755	3286	13041
February	46261	12317	3074	15391
March	18522	4631	3059	7690
April	9456	2035	3063	5098
May	18159	1543	1933	2478
June	26109	2051	2148	4649
July	33959	2530	2220	5073
August	34241	2377	2220	4692
September	15301	1182	1217	2529
October	7192	1096	2841	3937
November	18517	4306	3180	7486
December	35300	8842	3596	12438
Heating total	173129	42982	22099	65081
Cooling total	127769	9683	9738	19421
Annual balance	300898	52665	31837	84502

9. Conclusion

The electric energy demand for the administrative building during the heating season is 65 MWh per year and during the cooling season is 19.4 MWh per year. Overall electric energy demand to drive the heat pump and other circulation pump in the system is about 84.4 MWh per year. Calculated amount of electricity produced by photovoltaic system is 80.7 MWh. According to annual energy balance of heating and cooling system, we can say that the energy demand will cover 96% with electric energy that will be produced with the proposed photovoltaic system. If the parameters of photovoltaic panels will increase in the future, there is possibility to say that whole system during the year will be fully covered with electric energy that is produced through the photovoltaic system. On the other side we should say, that we need to cover additional energy demands for lightning and also for electric equipments in the offices. This could be possible, if the peak power of one photovoltaic panel will be around 300 Wp. After these system modifications we will be able to say that evaluated administrative building will be building with zero-energy balance, which mean that administrative building will be completely self-sustaining. It is effective if we could cover the energy consumption on the base of yearly energy balance.

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