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Analysis of solar collectors' use in a single family house in Poland and Spain- a case study

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Abstract. Renewable energy sources, especially solar radiation used in solar systems, have become popular lately although it is worthy to note that types of installations used and shares of renewable energy sources differ between European countries significantly. Main rules of selection of solar collectors, their advantages and the most important parameters determining the solar collector efficiency (as the structure, the flow rate of the heating medium, the effect of connection into batteries) were described in [1]. Methods that can be used during analysis of solar energy available as well as parameters influencing effective radiation, for instance shading were presented in [2-5]. In this paper we analysed a single family house with horizontal roof located in two countries: Poland and Spain. In both locations during analysis we took into account an influence of climatic conditions, national rules, companies' recommendations, cost of installation of the system, price of optional energy generation etc. We estimated Simple Payback Time (SPBT) for two types of collectors: flat-plate and vacuum pipe ones and noted specific national and European Union financial programs dedicated new installations. Results help to understand differences in development of solar energy market in chosen countries.

1. Introduction

Necessity of using alternative energy sources in order to stop negative environmental changes is reflected in Polish and European Union law [6-8]. In most European countries significant awareness increase is seen in relations to necessity of reduction of the energy consumption for heating, cooling and lighting purposes in buildings [9]. It is worth noting that a considerable amount of energy is consumed by the building sector and major outcomes can be gathered to approach zero or nearly zero energy building by handling renewable energy technologies [10].

In Poland the increase in percentage of renewable energy installations is observed. In sector of residential houses solar collectors are used mostly to domestic hot water preparation, while lately their share as a source for swimming pools and heating systems [11]. In case of usage collectors in HVAC systems it is better to install them in newly constructed objects since installing them in existing buildings most often requires a modernization of a heating system. Moreover it is necessary to note that in a Polish climate a solar installation needs additional energy source during autumn–winter period [11,12]. In the climactic conditions of Central Europe, a significant amount of energy is

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contained in diffuse sky radiation, so direct absorption solar collectors are used most frequently than concentrating solar collectors [13]. Most popular are plate and tube vacuum collectors that differ in structure, efficiency, however place and way of their montage, amount etc. are dependent mostly on geographic location [14-15]. In a local scale, the profitability of the use of solar collectors is shaped by the type and geometry of roofs as well as the effect of shading caused by the building's elements or high plants in a surrounding. The economic environment in this type of investments is created individually in different countries, together with national support systems, which often can reduce or even eliminate disparities in the availability of solar resources on EU territory [2-3].

Lasts years many users of residential buildings got financial support from programs focused on systems with renewable energy sources solar collectors. However most of them are referred to residences of particular region.

For instance, in Podlasie province, there are few possibilities within the framework of the Regional Operational Program Podlaskie years 2014 – 2020. In period 2017-2019 owners of houses are able to apply for money to replace 225 their old coal boiler by a new gas one and install 225 systems of solar collectors. Habitants own contribution is 15% of total costs [16]. Similar investment was finished in Choroszcz near Bialystok, where 380 houses were equipped in plate solar collectors, tanks etc. In this case a grant-aid was 80% of total qualify costs [17]. In another country borough grant was predicted for 132 houses to apply solar collectors, PV panels or heat pumps [18]. In Supraśl about 200 systems were installed and in 2017 next 100 is going to be finished [19].

This study compares the use of solar energy for Heating and DHW in Poland with a country with long history of renewable energy applications, Spain. Spain is one of first leaders in European Union and in the World. According to the Report of REN21 (Renewable Energy Policy Network for the 21th Century) [20], Spain is between the first 20 countries in the energy production of energy by these methods, with a coverage of more of 20% of total energetic demand of Country. The National Policy of economic incentive of the late twentieth century and favorable weather conditions have led to continued growth in the use of renewable energies from 1998 to the present. Although the economic crisis of 2007 has meant a decrease in this growth.

The use of renewable energy for buildings in Spain is regulated by Spanish CTE (Technical Code for Building) [21], that established measures to control energy consumption in houses and public buildings. This law obligates that a percentage of the energy consumption of new buildings and important renovation is covered by renewable sources. So, the use of collectors for heating and DHW or photovoltaic panels for electricity are mandatory in new houses designs

Also, Programs for financial support of solar collector in houses have been established in Spain, with European Fund for Regional Development. The management of these Programs corresponds to the Regional Governments. In Andalusia, Program “Sustainable Energy Development of Andalusia 2009 "Andalucía A +" of Regional Governments (Junta de Andalucia) allowed to subsidize up to 60% of the initial investment of the Solar installation during period 2009-2015. In the new Program for period 2016-17, this support is reduced to 40% [22].

In this paper, we analyze a single family house with roof located in two countries, determining energy consumption according the national building regulations. The maximum solar energy contribution is estimated for two type of collector: flat-plate and vacuum pipe. An exhaustive economic study is done where cost saved by the use of these solar collectors with different additional energy sources are calculated. Simple Payback times (SPBT) for respective installations are calculated, determining the influence of regional financial supports in these SPBT times.

2. Description of an analysed house

The house taken into analysis has two floors and no basement and is design for 4 people (Figure 1). On the first floor a kitchen, living and dining rooms, hall, a bathroom and a boiler room are located while there are rooms, bathrooms and wardrobes on the second floor. Total usable area is 170 $m^2$and the house is directed to the South.

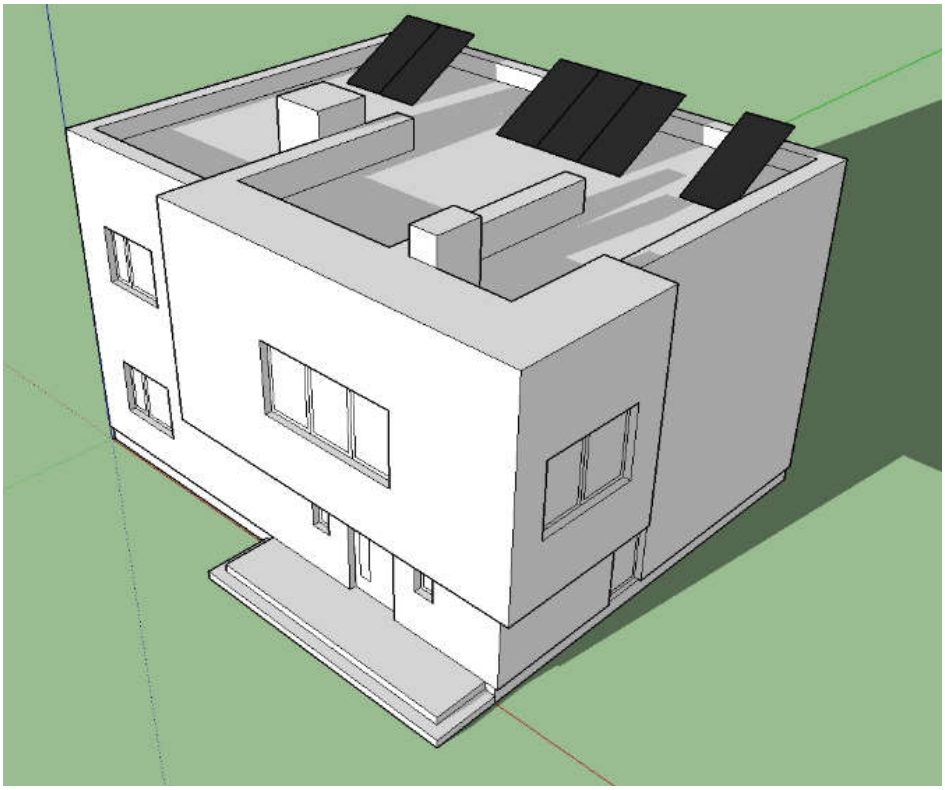

Figure 1. Visualization of an analyzed house.

Two locations of the house were taken into account: Bialystok (Poland) and Cordoba (Spain).These cities have two climatic conditions very different. Main climatic values for both towns are shown in Table 1 and Table 2 and localization are presented in Figure 2.



Figure 2. Location of the analyzed house.

Table 1. Basic parameters for Bialystok and Cordoba [23].

Parameter		*Białystok*	*Cordoba*
Geographic localization		53°07'North latitude 23°10'East longitude	37°53' North latitude 4°46' West longitude
Insulation time	h/year	1780	2900
The minimum daily global radiation on horizontal area	kWh/(m^{2}day)	0.52 (December)	2.00 (January)
The maximum daily global radiation on horizontal area	kWh/(m^{2}day)	4.76 (June)	7.92 (July)
Climatic temperature zone	-	4	B4
The minimum monthly temperature	°C	-4,9 (January)	+ 9 (January)
The maximum monthly temperature	°C	+17,3 (July)	+28 (July-August)

Table 2. Monthly Climatic Parameters for Bialystok [24,25] and Cordoba [26].

Month	*Global radiation on horizontal area kWh/(m^{2}day)*		*Air Temperature °C*		*Network Water Temp. °C*	
	Bialystok	*Cordoba*	*Bialystok*	*Cordoba*	*Bialystok*	*Cordoba*
January	0.67	2.00	-4.90	9.	6.5	6
February	0.99	2.81	-2.00	11	5.8	7
Mach	1.93	4.19	1.70	13	6.2	9
April	3.13	5.14	7.30	16	7.7	11
May	4.42	6.06	13.20	19	9.9	12
June	4.76	7.19	15.90	24	12.1	13
July	4.49	7.92	17.30	28	13.9	14
August	3.72	6.97	14.50	28	14.7	13
September	2.82	5.53	12.10	24	12.1	12
October	1.30	3.50	7.10	19	12.7	11
November	0.66	2.39	1.60	14	10.5	9
December	0.52	1.92	-1.30	10	8.3	6

3. Methodology

For both locations of the analyzed house we estimated useful energy needs for heating and hot water systems. The scheme of the installation is shown in Figure 3.

3.1. *Energy for heating*

During calculations of energy load we used Auditor OZC Edu software[27] national standards and regulations [21,28]. Because values of heat transfer coefficients in Poland and Spain differ significantly (Table 3) the calculations were conducted for variants: firstly with assumption that all external envelope components met requirements of Polish rules, secondly for Spanish values. Windows in both locations were considered as having U=1.1 W/(m^{2}K).

Table 3. Maximum values of heat transfer coefficients U[29][21].

Barrier		*Białystok*	*Cordoba*
Floor on the ground	W/(m^{2}K)	0.29	0.52
External walls	W/(m^{2}K)	0.23	0.82
Roof	W/(m^{2}K)	0.19	0.45

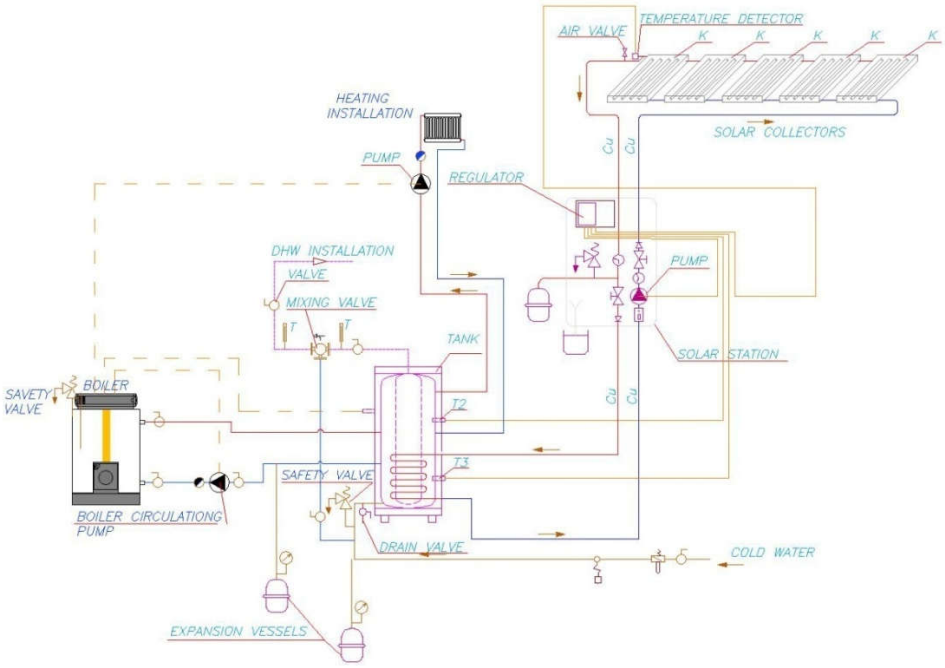

Figure 3. Scheme of the Heating-DHW solar system.

3.2. *Energy for hot water*

To estimate energy for hot water preparation our assumption was that 30 dm^3 per person in 60ºC is needed as shown in [21], because in Polish documents the value varies significantly from 30 to 120 dm^3/(person day) [2].

This energy is estimated for every month according to the equation:

$$Q(GJ) = C_e D_i \rho \left({T_H}^i - {T_N}^i \right) \quad (1)$$

where C_e and ρ are specific heat capacity and density of water, D_i is hot water demand in i month, T_H^i is storage temperature of hot water (60ºC is assumed) and T_N^i is temperature of network water in this month.

3.3. *Estimation of collectors' number, a cost of system and monthly share of energy obtained from solar collectors*

Maximum number of collectors possible to use was estimated with assumption that rows of them should be in minimum distance calculated from Eq.2:

$$d_{min} = l\left(\frac{sin\beta}{tg\ h} + cos\beta\right) \quad (2)$$

where l and β are length and tilted angle of solar collectors and h is sun altitude at 12:00 pm of 21th December.

In this study, we have worked with flat-plate and vacuum pipe collector with typical technical characteristics show in table 4. For these collectors, minimum distances obtained from Eq. 2 are 7 m in Bialystok, while 3.8 m in Cordoba.

According to these distances, maximum number of collectors is 6 for Poland and 16 for Spain (Figure 6). Although, in this last localization, a number higher than 6 has been demonstrated that is not improving the results and it could be reason of over-dimension and over-cost of installation. So, we have chosen this number in our calculations, giving a total collection area of 12 m^2.

Table 4. Typical collectors parameters used in this work.

	Length (m)	*Area (m^2)*	*Optical efficiency*	*Heat loss factor (W/m^2K)*	*Tiled Angle β (º)*	*Azimuth angle of the solar collector surface α (º)*
Flat-Plate	1.9	2.0	0.75	4.0	45	0
Vacuum Pipe	1.9	2.0	0.8	1.1	45	0

Maximum energy gains from 6 solar collectors in these conditions were estimated using the e-lab "Estimation of Energy Gains from Solar Collectors" developed for Erasmus+ Project VIPSKILLS [30].An energy loss factor of 8% is estimated for the total installation [31]. The storage tank used was 1000 liters capacity according to some companies recommendations.

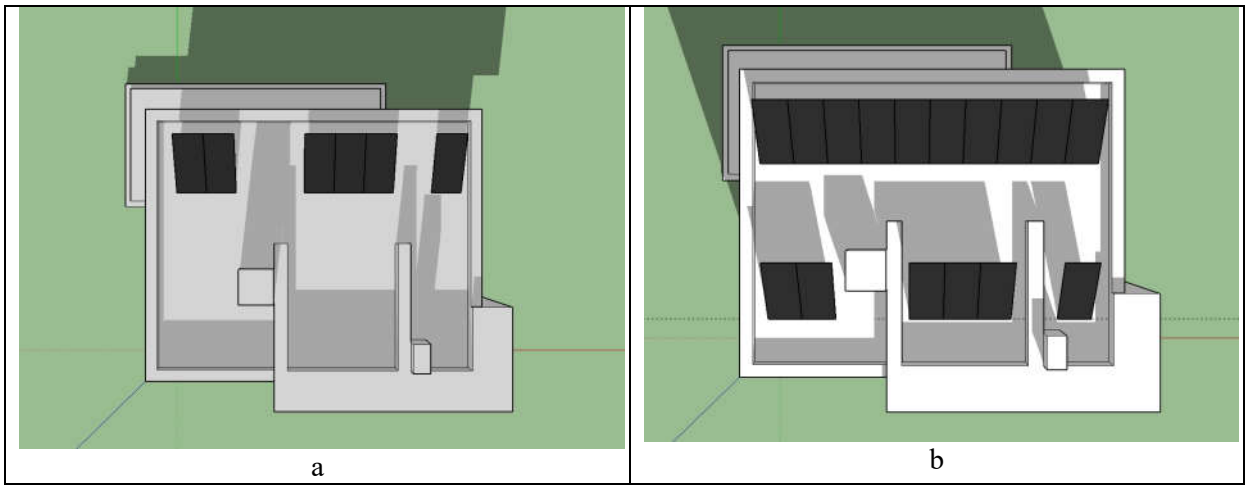

Figure 4. Plan of the roof with maximal number of solar collectors a) Poland b) Spain.

For cost calculations main elements of the system (Figure 3) were taken into account, based on real prices given in market price lists (Table 5).In order to estimate Annual Energy Cost Savings and Simple Payback of installations, we have used actualized prices of different energy sources in every country (Table 6).

Table 5. Prices of installation with different additional energy supplies.

Cost (€)	*without additional energy supply*	*with Electric boiler*	*with Fuel-oil boiler*	*with Natural Gas/LPG boiler*	*with Pellet boiler*	*with Wood/Coal boiler*
Flat Plate	8613	9913	9848	9523	11278	11213
Pipe Vacuum	11398	12698	12633	12308	14063	13998

Table 6. Prices of energy sources for heating and DHW in Poland and Spain.

Cost (€/kwh)	*Electric*	*Fuel-oil*	*Natural Gas*	*Bottled LPG Gas*	*Pellet*	*Wood*	*Coal*
Poland	0.13	0.06	0.04	0.09	0.05	0.04	0.04
Spain	0.14 (including taxes)	0.058	0.05	0.084	0.06	0.045	0.058

4. Results

4.1. Bialystok localization

Table 7 shows energy load for heating and DHW in Bialystok with a construction that complied with Polish U_{max} values, and if the house would be built according to Spanish regulations (although this variant could be taken into account only as an old building in Poland because all new objects must stick to Polish rule). The energy consumption in the case of Polish construction is almost half of Spanish one.

Table 7. Energy load for heating and DHW in Bialystok.

month	*Energy for heating [GJ]*		*Energy for DHW [GJ]*	*Total Monthly energy demand [GJ]*	
	U according to Polish law	*U according to Spanish law*		*U according to Polish law*	*U according to Spanish law*
January	9.04	17.40	0.88	9.92	18.28
February	8.55	16.47	0.81	9.36	17.28
March	8.15	16.04	0.89	9.04	16.93
April	5.53	11.50	0.82	6.35	12.32
May	3.87	8.54	0.79	4.66	9.33
June	0	0	0.70	0.70	0.70
July	0	0	0.67	0.67	0.67
August	0	0	0.65	0.65	0.65
September	1.69	4.13	0.64	2.33	4.77
October	4.92	9.68	0.70	5.62	10.38
November	7.39	13.96	0.74	8.13	14.70
December	8.95	16.94	0.83	9.78	17.77
Annually	**58.10**	**114.66**	**9.12**	**67.21**	**123.78**

For Polish localization, Table 8 and 9 show maximum Energy Gains from flat-plate and vacuum pipe collectors, respectively. In these tables, total value of saved energy for every month and percentage of solar energy cover are shown. As can be observed, no big differences are found between Energy Gains with construction according to Polish law and Spanish law. But the percentage of Solar contribution respect to total energy demand is very different.

In case of constructing following the Polish law, the solar energy can cover 20.48% of annual energy load for heating and DHV when flat-plate collectors are used and 24.28% with vacuum pipe collectors. When the construction is according to Spanish regulation, solar contribution is only 11.12% for the flat-plane collector and 13.50% for the vacuum pipe.

As has been mentioned, vacuum pipe collector is given higher solar contribution. Question is if this increment in contribution is compensated by higher cost of installation when vacuum pipe collectors are used. Answer depends of the cost saving due to solar energy. Annual reductions of energy bills by the use of solar energy together simple payback time (SPBT) of installations investment are shown in Table 10 and 11 for the different sources for additional energy supply.

The SPBT is varying between 20 years for most expensive electricity to 77 years in the case of cheap wood and coal. Despite the highest efficiency found with vacuum pipe collectors, SPBT is higher with these collectors due to higher prices of these systems. These values of SPBT are unacceptable considering that average life time of a solar collector installation is about 25 years. However its worthy to note that we considers a system in the new house, so all necessary devices, fixture and fittings were taken into account. In case of an existing object the prices would be lower by costs of additional energy source, tank and part of armature, so SPBT would be 5-10 years shorter, depending on additional source. Later, effect of economic support Programs in this SPBT will be analyzed.

Table 8. Solar contribution for heating and DHW with flat-plate in Bialystok localization.

month	*Energy Gains [GJ]*	*U according to Polish law*			*U according to Spanish law*		
		Heat Load [GJ]	*Saved Energy [GJ]*	*Percent. Saved Energy [%]*	*Heat Load [GJ]*	*Saved Energy [GJ]*	*Percent. Saved Energy [%]*
January	0.00	9.92	0.00	0.00	18.28	0.00	0.00
February	0.40	9.36	0.40	4.32	17.28	0.40	2.34
March	1.74	9.04	1.74	19.28	16.93	1.74	10.29
April.	2.96	6.35	2.96	46.61	12.32	2.96	24.02
May	4.14	4.66	4.14	88.89	9.33	4.14	44.40
June	3.95	0.70	0.70	100.00	0.70	0.70	100.00
July	3.73	0.67	0.67	100.00	0.67	0.67	100.00
August	2.87	0.65	0.65	100.00	0.65	0.65	100.00
September	2.09	2.33	2.09	89.85	4.77	2.09	43.89
October	0.40	5.62	0.40	7.09	10.38	0.40	3.84
November	0.00	8.13	0.00	0.00	14.70	0.00	0.00
December	0.00	9.78	0.00	0.00	17.77	0.00	0.00
Annually	**22.29**	**67.21**	**13.76**	**20.48**	**123.78**	**13.76**	**11.12**

Table 9. Solar contribution for heating and DHW in Bialystok with vacuum pipe collector.

month	*Energy Gains [GJ]*	*U according to Polish law*			*U according to Spanish law*		
		Heat Load [GJ]	*Saved Energy [GJ]*	*Percent. Energy saving [%]*	*Heat Load [GJ]*	*Saved Energy [GJ]*	*Percent. Saved Energy [%]*
January	0.41	9.92	0.41	4.13	18.28	0.41	2.24
February	0.79	9.36	0.79	8.44	17.28	0.79	4.57
March	1.98	9.04	1.98	21.90	16.93	1.98	11.70
April.	3.00	6.35	3.00	47.24	12.32	3.00	24.35
May	4.07	4.66	4.07	87.34	9.33	4.07	43.62
June	3.99	0.70	0.70	100.00	0.70	0.70	100.00
July	3.93	0.67	0.67	100.00	0.67	0.67	100.00
August	3.41	0.65	0.65	100.00	0.65	0.65	100.00
September	2.72	2.33	2.33	100.00	4.77	2.72	57.02
October	1.15	5.62	1.15	20.46	10.38	1.15	11.08
November	0.33	8.13	0.33	4.06	14.70	0.33	2.24
December	0.24	9.78	0.24	2.45	17.77	0.24	1.35
Annually	**26.01**	**67.21**	**16.32**	**24.28**	**123.78**	**16.71**	**13.50**

Table 10. Annually costs saving (€) with solar energy and SPBT (years) for different sources of additional energy supply in Bialystok.

U according to	*Flat-plate collector*				*Vacuum pipe collector*			
	Polish law		*Spanish law*		*Polish law*		*Spanish law*	
	Saved cost	*Payback*	*Saved cost*	*Payback*	*Saved cost*	*Payback*	*Saved cost*	*Payback*
Electricity	496.89	20	496.89	20	589.33	21	603.42	21
Fuel-oil	229.33	43	229.33	43	272.00	46	278.50	46
Nat. Gas	152.89	62	152.89	62	181.33	68	185.67	66
LPG	344.00	28	344.00	28	408.00	30	417.75	29
Pellet	191.11	59	191.11	59	226.67	62	232.08	60
Wood	152.89	73	152.89	73	181.33	77	185.67	75
Coal	152.89	73	152.89	73	181.33	77	185.67	75

4.2. Cordoba localization

Table 11 shows the energy load for Cordoba location. Due to its higher temperatures, we found a lower energy load, especially in spring-summer months. Also, in this location, highest load corresponds to construction using Spanish law. But differences are not as high as in Poland.

Table 11. Energy load for heating and DHW in Cordoba.

month	*Energy for heating [GJ]*		*Energy for DHW [GJ]*	*Total Monthly energy demand [GJ]*	
	U according to Polish law	*U according to Spanish law*		U according to Polish law	*U according to Polish law*
January	3.27	5.89	0.84	4.11	6.73
February	3.07	5.34	0.75	3.82	6.09
March	2.25	4.32	0.79	3.04	5.11
April	1.25	2.55	0.74	1.99	3.29
May	0	0	0.75	0.75	0.75
June	0	0	0.71	0.71	0.71
July	0	0	0.72	0.72	0.72
August	0	0	0.73	0.73	0.73
September	0	0	0.72	0.72	0.72
October	0.30	0.56	0.76	1.06	1.32
November	2.27	3.90	0.77	3.04	4.67
December	4.07	6.94	0.84	4.91	7.78
Annually	**16.46**	**29.51**	**9.11**	**25.59**	**38.61**

Results of solar contribution of installation with flat-plate and vacuum pipe collectors are shown in Table 12 and 13. Also climatic conditions are given higher values of solar contribution. In this case, percentage of energy saved is 86.12 % when Polish law is following in building construction and 67.61% for Spanish law. Contrary to Bialystok, vacuum pipe have proven to be less effective in this location, reducing the percentages of energy saved.

Table 12. Solar contribution for heating and DHW with flat-plate collectors in Cordoba location.

month	*Energy Gains [GJ]*	*U according to Polish law*			*U according to Spanish law*		
		Heat Load [GJ]	*Saved Energy [GJ]*	*Percent. Energy saving [%]*	*Heat Load [GJ]*	*Saved Energy [GJ]*	*Percent. Saved Energy [%]*
January	2.87	4.11	2.87	69.79	6.73	2.87	42.62
February	3.38	3.82	3.38	88.42	6.09	3.38	55.46
March	4.89	3.04	3.04	100.00	5.11	4.89	95.73
April.	5.26	1.99	1.99	100.00	3.29	3.29	100.00
May	6.03	0.75	0.75	100.00	0.75	0.75	100.00
June	7.05	0.71	0.71	100.00	0.71	0.71	100.00
July	8.46	0.72	0.72	100.00	0.72	0.72	100.00
August	8.41	0.73	0.73	100.00	0.73	0.73	100.00
September	7.21	0.72	0.72	100.00	0.72	0.72	100.00
October	5.31	1.06	1.06	100.00	1.32	1.32	100.00
November	3.69	3.04	3.04	100.00	4.67	3.69	79.04
December	3.04	4.91	3.04	61.94	7.78	3.04	39.09
Annually	**65.60**	**25.59**	**22.05**	**86.12**	**38.61**	**26.11**	**67.61**

Reduction of energy bills and SPBT in Cordoba location have been also calculated (Table 14). Significantly greater energy savings are found and shorter SPBT compared to Bialystok. However, SPBT are still very high compared to the life time of installations, except when electricity is used as additional source of energy, because of its high price. This makes also the investment economically unviable in this case.

Table 13. Solar contribution for heating and DHW with vacuum pipe collectors in Cordoba location.

month	*Energy Gains [GJ]*	*U according to Polish law*			*U according to Spanish law*		
		Heat Load [GJ]	*Saved Energy [GJ]*	*Percent. Energy saving [%]*	*Heat Load [GJ]*	*Saved Energy [GJ]*	*Percent. Saved Energy [%]*
January	2.78	4.11	2.78	67.64	6.73	2.78	41.31
February	3.26	3.82	3.26	85.34	6.09	3.26	53.53
March	4.84	3.04	3.04	100.00	5.11	4.84	94.72
April.	5.16	1.99	1.99	100.00	3.29	3.29	100.00
May	5.78	0.75	0.75	100.00	0.75	0.75	100.00
June	6.52	0.71	0.71	100.00	0.71	0.71	100.00
July	7.71	0.72	0.72	100.00	0.72	0.72	100.00
August	7.57	0.73	0.73	100.00	0.73	0.73	100.00
September	6.60	0.72	0.72	100.00	0.72	0.72	100.00
October	4.92	1.06	1.06	100.00	1.32	1.32	100.00
November	3.48	3.04	3.04	100.00	4.67	3.48	74.52
December	2.87	4.91	2.87	58.45	7.78	2.87	36.89
Annually	**61.49**	**25.59**	**21.67**	**84.65**	**38.61**	**25.47**	**65.95**

Table 14. Annually costs saving (€) with solar energy and SPBT (years) for different sources of additional energy supply in Cordoba.

U according to	*Flat-plate collector*				*Vacuum pipe collector*			
	Polish law		*Spanish law*		*Polish law*		*Spanish law*	
	Saved cost	*Payback*	*Saved cost*	*Payback*	*Saved cost*	*Payback*	*Saved cost*	*Payback*
Electricity	857.50	12	1015.4	10	842.72	15	990.50	13
Fuel-oil	355.25	28	420.66	23	349.13	36	410.35	31
Natural Gas	306.25	31	362.64	26	300.97	41	353.75	35
LPG	514.50	18	609.23	16	505.63	24	594.30	21
Pellet	367.50	31	435.17	26	361.17	39	424.50	33
Wood	275.63	41	326.38	34	270.88	52	318.38	44
Coal	355.25	32	420.66	27	349.13	40	410.35	34

4.3. Comparison of both locations

Figure 5 shows the comparison of energy load and solar energy gains using flat-plate collectors. We can observe that percentage of solar energy is much higher in Cordoba than in Bialystok, especially when house construction is following the Polish law with 86.12%.

Cordoba presents high contributions during all months of the year. Contrary, in Bialystok, we obtain an important contribution only during spring and summer, being mandatory the use of additional energy sources during the rest of year.

Energy load and solar energy gains for 6 vacuum pipe collectors in Bialystok and Cordoba are shown in Figure 6. Behavior is similar to the one found with flat-plate collectors. While the use of vacuum pipe collector means an improvement in the solar contribution in Bialystok, we observe that solar contribution is reduced with these collectors in Cordoba, due to their less efficiency in the climatic conditions of this city.

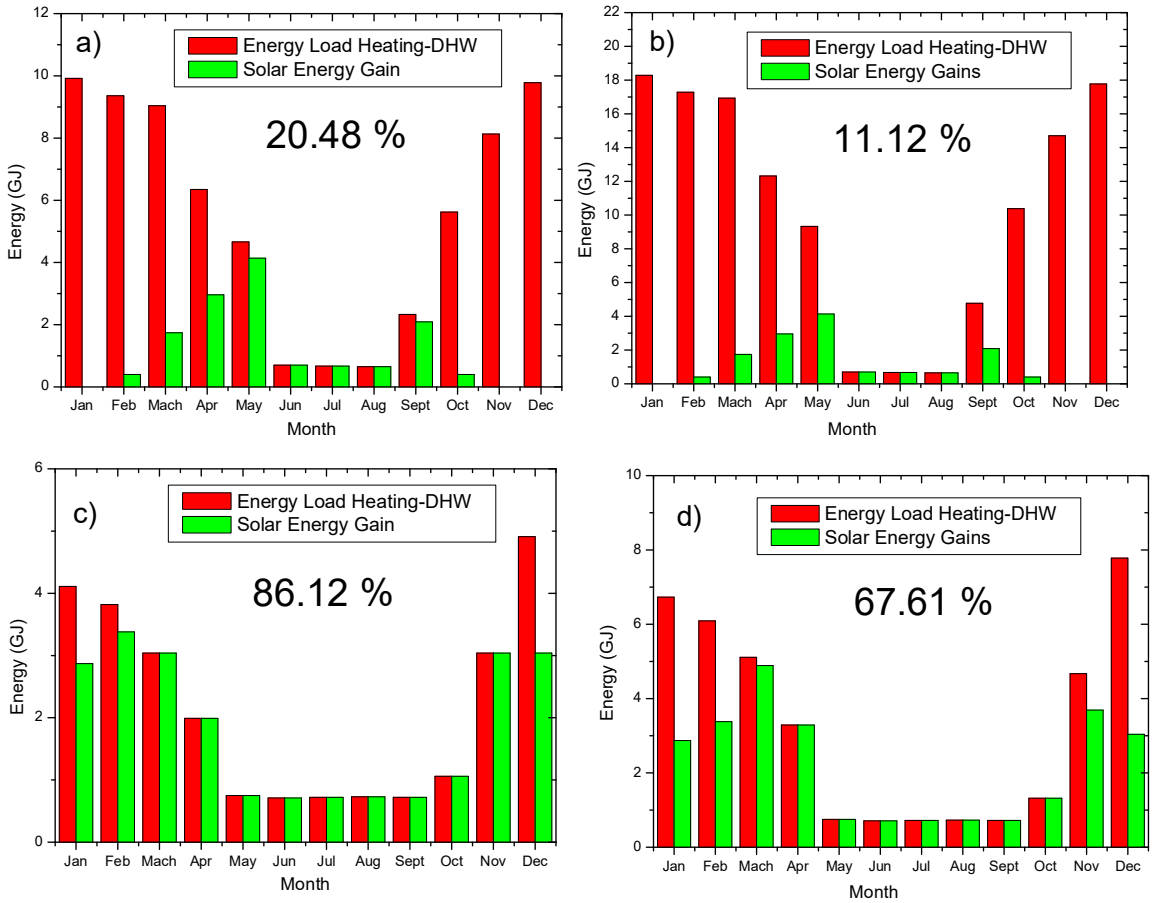

Figure 5. Energy Loads and Solar energy gains for 6 flat-plate collectors in Bialystok with house construction according to Polish law a) and Spanish law b) and in Cordoba according Polish law c) and Spanish law d). The percentage of solar energy contribution is put in each figure.

Regardless of previous results, as we mentioned in previous subsection, SPBT too high to make the end consumer's investment profitable in this type of technology. The effect of regional economic aid on the implementation of solar collectors has also been studied. The variation of the SPBT with these aids has been determined. We have used the maximum values of these aids for each location. The results are shown in Table 15.

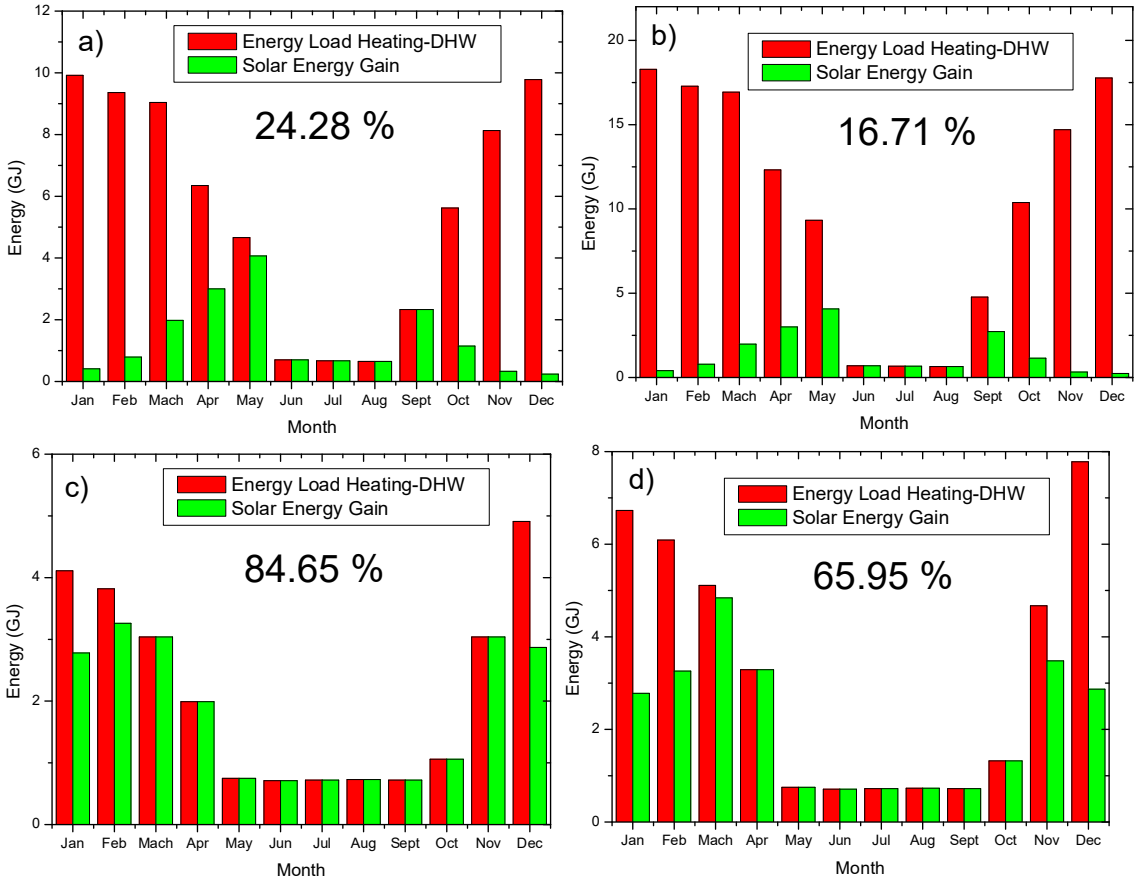

Figure 6. Energy Loads and Solar energy gains for 6 vacuum pipe collectors in Bialystok with house construction according to Polish law a) and Spanish law b) and in Cordoba according Polish law c) and Spanish law d). The percentage of solar energy contribution is put in each figure.

Payback times are reduced in both cases to values lower or similar to life time of installations, which ensures the viability of the project for the investor, Also we can observe that obtained times are very similar in both locations, which indicates that regardless of high difference in the availability of solar resources on these countries, regional support policies allow to reduce or eliminate these differences in the project profitability. In case of existing building under modernization we would receive in Poland SPBT from 3.2 to 10.5 years, while in Spain in range 3.7-11.6 years.

Table 15. Simple Payback times with financial support by Regional Programs in Bialystok and Cordoba.

	Simple Payback Time (years)							
	Bialystok (maximum support 80%)				*Cordoba (maximum support 60%)*			
	U according to Polish law		*U according to Spanish law*		*U according to Polish law*		*U according to Spanish law*	
	Flat-Plate	*Vacuum pipe*	*Flat-Plate*	*Vacuum pipe*	*Flat-Plate*	*Vacuum pipe*	*Flat-Plate*	*Vacuum pipe*
Electricity	4	5	4	4	5	6	4	5
Fuel-oil	8	9	8	9	11	14	9	12
Natural Gas	12	14	12	13	12	16	10	14
LPG	6	6	6	6	7	10	7	8
Pellet	12	12	12	12	12	16	10	13
Wood	15	16	15	15	16	21	14	18
Coal	15	16	15	15	13	16	10	14

5. Conclusions

This work studies solar collectors' use in a single family house in Poland and Spain. The same build, built according to Polish and Spanish regulations, is analyzed in both locations using two type of collectors: flat-plate and vacuum pipe.

This study showed that very different energy loads for heating are found if the house is built according to Polish and Spanish laws. Maximum permitted values of heat transfer coefficients for external barriers are 1.8-3.5 times lower in Poland than in Spain, and they will be decreased further according to Polish law. Construction of an analyzed house with U following Polish regulation located in Cordoba allows to reduce the energy demand by half, however energy for heating is significantly lower in Spain: 2.5-3.5 times comparing to the house in Bialystok (depending on the construction).

Energy saved due to solar collectors system in a house located in Cordoba is in range 22.05-25.47 GJ for the house in both types of barrier construction and collector types. The highest contribution of solar energy (86.12%) was noted in case of plate collectors in the building under Polish recommendation about U values. It was about 20% more than estimated for the same house under Spanish construction law with pipe tube collectors. Energy solar saving in Poland were about 1.5 times lower than in Spain and differed only slightly between systems with plate and tube collectors (13.76-16.71 GJ). However, solar contribution for a house in Bialystok was significantly lower – even 6 times less than in Cordoba (11.12-24.28%)

Technical conditions of the roof, avoiding shadowing, allowed to install 6 collectors in Poland, what is significantly too less to cover energy needs, especially in winter, so collectors can work only additionally to main energy source. On the other hand in Cordoba possibility to install 16 collectors results in an over-dimension of the system and other than would case over-costs, it could also provide to technical problems with energy usage and accumulation.

It was demonstrated that vacuum pipe collectors give the best results for Bialystok location, but outcomes were opposite in Cordoba with a less solar contribution, confirming that this type of collectors is working better in a cold climate zone. In any case, high prices of vacuum pipe installation are not compensated by energy gains.

Finally, economic study of this case allows us to show that annually reductions of energy billswith solar collector gives payback times much higher of life time of installation, making this type of project economically unfeasible. Only, Programs of financial incentives for this type of energy allow consumers to tackle investment with a profitability. These Programs eliminate or reduce differences in the availability of solar resources between countries.

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