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Modeling of the Solar Thermal Energy Use in Urban Areas

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Abstract

Most of the generated electricity in Kosovo is produced from fossil fuel, a part of the energy comes from the import, while participation of renewable resources is symbolic, and a bias between the grid extension and the load of power generated sometimes results in shortage of electricity and thus frequent power cuts. The use of renewable energy and particularly the solar thermal energy represents one of the most promising alternative strategies. In Kosovo, the global horizontal radiation ranges from 1241 kWh/m^2 per year in Shterpce to 1461 kWh/m^2 per year in Gjakova, while the average for Kosovo can be estimated at 1351 kWh/m^2 per year. The average sun duration for the city of Pristine is 5.44 h, while the average horizontal irradiation is 3.79 kWh/m^2 per day. Participation of energy consumption in household is still dominant - about 41.4% of the total consumption in Kosovo, 15% of this energy is used for domestic hot water. This energy demand can be lowered significantly by using improved building construction techniques and utilization of RES-s, especially solar thermal. The first step is to map the city in different areas to locate suitable locations for the installation of solar collectors serving sanitary hot water. The demand for sanitary hot water varies from object to object, this variation depends on whether the building is individual or collective, school institutions or religious buildings, for this reason the classification of buildings was done according to the request for sanitary hot water. After that the demand for sanitary hot water is calculated for several different institutions: Residential houses, Dormitories and Hospitals. For all of the above-mentioned cases the data for: solar fraction, solar contribution, CO_2 avoided, collector temperature, financial analysis etc. are gained using the TSOL 2018 software. To evaluate the activation energy for a time period, the daily, monthly and annual performance for three systems which are located in University Clinical Center of Pristine, Kosovo have been analyzed. In addition the results of the mathematical model, simulation and measured solar energy contribution for solar station in Infective disease clinic have been compared. In this paper, a proposal for replacing the conventional water heaters with the domestic solar water heaters (DSWH) is made. A case study for 38289 Residential households in Pristine has been selected. The initial cost of the solar water heater for the city is 60113730 €. The system saves 7274910 € annually and reduced CO_2 emission by 22973400 kg. The results from the paper show that the DSWH is economically feasible in Pristine and can result in fuel saving and CO_2 emission reduction.

Keywords: Solar Thermal Energy; Domestic Hot Water; Renewable Energy; Energy Analysis; T*SOL2018; f-chart Method; Saving Electricity; CO_2 Reduction.

1. Introduction

Renewable Energy Sources (RES) are the object of ever increasing interest in their use in recent years. The main cause of this interest rise lies in the warning about the depletion of conventional energy sources on the planet: fuel, natural gas, coal and the end of uranium reserves by contrast, RES-s can be considered inexhaustible sources of energy at the human scale, as they use natural energy flows from the sun. Another reason for developing renewable energy sources is the uneven distribution of conventional energy sources on the planet, along with their uneven consumption,

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and maybe the important reason is the fight against emissions that cause many negative phenomena such as: greenhouse effect, stratospheric ozone depletion, global warming, etc. These harmful gases are emitted through various human activities, including the production of energy from conventional energy sources. Thus, the reduction of energy produced from conventional sources by increasing the share of RES will reduce their emissions and consequences.

Today approximately 79.5% of the primary energy use in the world is provided by fossil fuels, only about 18.2% by all renewable energy sources and 2.2% by nuclear power [1]. In Kosovo, electricity generation capacities are:

Power Plants,

Hydro Power Plants, and

Renewable Energy Sources (small hydro power plants, wind power plants and photovoltaic panels).

Around 93% of the primary energy is provided by fossil fuels, while participation of renewable resources is symbolic. Electricity consumption in distribution in 2017 is carried out in the amount of 4.997 GWh, while in 2016 was 4.807 GWh, which represents an approximate increase by 3.95% [2]. The highest consumption was carried out in Pristina district with 31.6% of the total consumption in distribution. Participation of energy consumption in household is still dominant - about 41.4% of the total consumption both in Kosovo and in Europe.

This energy demand can be lowered significantly by using improved building construction techniques and utilization of RES-s, especially solar thermal (for: domestic hot water, space heating and industrial heat process), which is not only renewable, but also clean in the sense that the conversion phase does not rise to any greenhouse gas emissions.

Thermal energy sector in Kosovo consists of 4 district heating systems, with an installed capacity considered to be around 332 MW_{th}:

DH Termokos – Prishtina,

DH Gjakova – Gjakove,

DH Termomit – Mitrovica, and

DH in Zvecan.

This sector has a fairly limited extent locally, fulfilling 3 - 5% of total heating demand in Kosovo. District Heating of Termom and Zveçan, due to notorious circumstances, have not responded to requirements for licensing/regulation and monitoring of ERO, thus making impossible to ensure relevant updated data; to this end.

In 2016/2017 season, the entire thermal energy production was from cogeneration plants in TPP Kosovo B, so the activation of boilers with heating oil in DH Termokos was unnecessary [2].

The amount of thermal energy extracted from cogeneration in 2016/2017 season was 225,438 MWh_{th}. The amount of thermal energy received in the heat exchange station in DH Termokos was 221,058 MWh_{th}. It should be noted that this represents an increase of around 13.5% compared to the production of the previous season.

The solar thermal market has an immense potential for growth, in 480GW_{th} on 2018, up from 472GW_{th} a year earlier, while 456 GW_{th} in 2016 [1]. The solar energy received by the Earth during an hour is greater than the total annual energy demand worldwide. It is obvious that we could profit from solar energy to a far greater extent than what is done today.

The biggest problem has been that the cost of solar thermal systems has not been low enough to make these systems competitive on the market. This trend is starting to change with rising energy prices, but it is not changing fast enough. In order to widen and increase the use of solar thermal energy there are several ways to deal with the issue. Legislation is one way, already practiced in some European countries. Governmental subsidies are another way, in which continuity is very important. Although the solar thermal collectors of today are already highly developed it is also important to continue the development of collectors and system designs in order to improve their efficiency, quality, life expectancy, profitability etc.

Despite global development, renewable energy sources are not a universal solution to power supply problems. This is due to some shortcomings. Most important is the lack of power guaranteed by generators, conversion of the main potential of electricity due to the stochastic nature of changes in the primary solar (photovoltaic or thermal energy) and wind sources. In the first case, variations are caused by the day-to-night cycle, through clouds in the sky, or other obstacles between the sun and solar installations. For wind turbines, energy variations are due to wind speed variability, and so on. In this way, the wind power, converted by wind turbines, into mechanical power, has a changeable character because it is proportional to the third-rate wind speed. This disadvantage is much less pronounced in the hydropower plants, due to the presence of water dams and thus prescribing the presence of a certain amount of water in them. In addition, the hydraulic machine's technological experience facilitates the implementation of this renewable energy source. Another serious problem faced by increasing the installed capacity of RES is the initial investment. It is high due to the high price of used materials. In addition to its high price, photovoltaic systems are characterized by low efficiency (less than 15% in real terms), which further limits their distribution, thermal environments in this regard are better, because their efficiency reaches up to 80% [3]. Solar domestic hot water cost in Europe is around Euro 50-160 per MWh of heat, which is usually more expensive than heat from natural gas in urban areas, (Renewable Energy Essentials). Although we will face great challenges, we are sure that we will increasingly use renewable energy sources for the reasons mentioned above (exhaustion of fossil fuels and climate change problem).

2. Environmental Characteristics and Mapping of Appropriate Surfaces for Installation of Solar Thermal Collectors

This part provides a detailed theoretical analysis of environmental characteristics for the city of Prishtina, as well as did the mapping of appropriate surfaces for installation of solar thermal collectors.

Solar Radiation - Pyranometers are instruments for measuring global radiation (direct and diffuse). The following Table 1 clearly shows that the average solar radiation differs from a minimum of 1.38 (kWh/m^2/day) in December to a maximum of 6.44 (kWh/m^2/day) in July, but the average is 3.79 (kWh/m^2/day).

Table 1. Horizontal Irradiation city of Pristine (kW·h/m^2)

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Anual
Daily	1.64	2.44	3.41	4.31	5.24	6.18	**6.44**	5.70	4.15	2.80	1.75	**1.38**	**3.79**
Monthly	50.90	68.44	105.68	129.37	162.60	185.65	199.69	176.83	124.51	87.03	52.68	42.90	1386.32

Determination of Sunshine Duration - The instrument widely used to measure the duration of sunshine is called Heliograph**.** Monitored over a period of 15 years by the Hydrometeorological Institute of Kosovo. Table 2, it shows that the average of sunny hours is 5.44 (h), also the table highlights the existence of huge differences between the different seasons of the year, this difference varies from a minimum of 66.62 (h) for December, to a maximum of 287.03 (h) in July.

Table 2. Insolation (h) city of Pristine

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Anual
Daily	2.39	3.41	4.71	5.72	7.12	7.60	9.26	8.71	6.25	4.60	3.37	2.15	**5.44**
Monthly	74.10	95.70	146.14	171.76	220.3	228.05	**287.03**	269.95	187.6	142.48	100.89	**66.62**	165.48

Air Temperatures – is another important factor that is analyzed for the city of Pristine for period 2001-2017 - The distribution of air temperatures in the territory of Kosovo presents a considerable variability. The highest average temperature for a year is in Prizren 12°C, the lowest temperature in Podujevo 9°C, Pristine 11.3°C, while the average annual temperature of Kosovo for year is 9.5°C, Figure 1 presented the minimum, average and maximum air temperature for Pristine city.

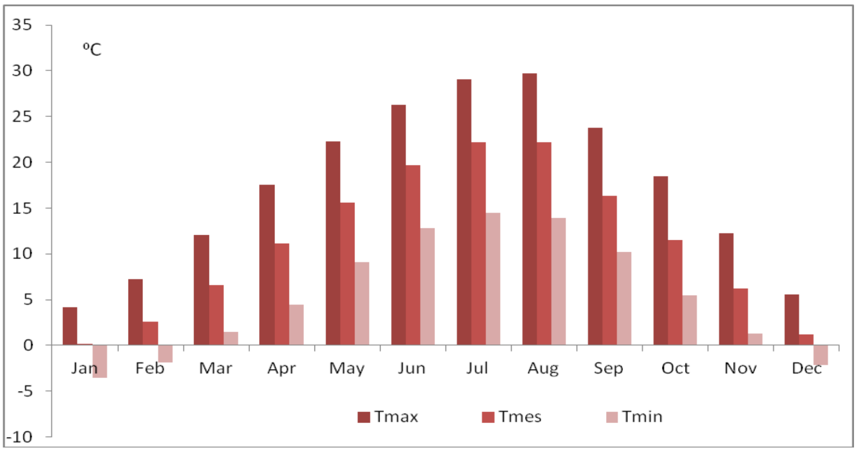


Figure 1. Monthly average air temperatures (in °C) during the period 1981-2017

The mapping of appropriate surfaces for installation of solar thermal collectors. Pristine is the capital city, and the biggest city in Kosovo. Located at coordinates 42°40'0" North and 21°10'0" East, Figure 2a). The surface of the Municipality of Pristine is about 523 km^2. The climate is continental, with cold winters and hot summers, the precipitation average of about 600 mm per year.

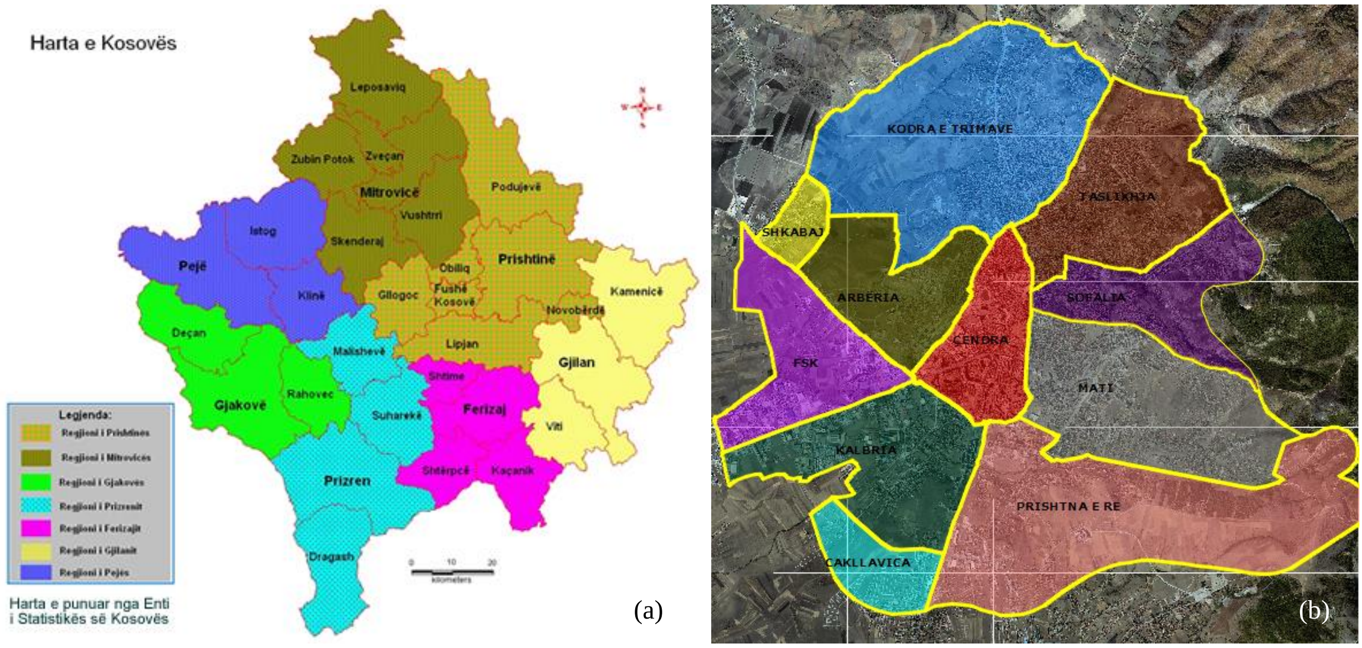


Figure 2. a) Map of Kosovo [4]; b) Map of Pristine divided in some areas

To locate suitable locations for the installation of solar collectors serving sanitary hot water, the first step is to divided the city in some areas Figure 2b). The second step is to calculate the roofs area for city of Pristine, which area estimates the space available for solar thermal installation [5]. To estimate how much energy could be generated from the sun on a surface, first the area should be calculated to see how many solar panels could be placed on it. There are various roof tops measuring tools online or software, the software AutoCAD is used Figure 3.

Figure 3. The roof surface which is appropriate for installing solar collectors

To analyze the appropriate roof space for solar collector installation, the division of the city into some areas is made:

New Pristine - is an area that is predominantly inhabited by individual housing and very little in multiple residential building single. The surface suitable for installing solar collectors is 86957.54m^2.

Taslixhja - includes a large part of the city, it is inhabited by single or multiple residential buildings, the houses are so dense that appear as a barrier because some objects are completely in the shade, then many roofs have windows that reduce the appropriate roof surface. The surface suitable for installing solar collectors is 340393.562m^2.

Shkabaj - this area connects the city of Pristine with Obiliq, has a small surface, in this area there are mainly individual housing, while the roof surface that can be used for solar collector installation is 17041.61 m^2.

Mati - This area is very well organized, with multiple residential building, but there is also individual housing and can be stated as very suitable for the application of solar energy.The surface suitable for installing solar collectors is 295747.7m^2.

Arberia- has a big area of the city but is less inhabited, mostly with individual housing. The appropriate surface for installation of solar collectors is 126272.42 m^2.

Sofali- is the part that has most greener, also in this part we have collective and individual housing. The appropriate surface for installation of solar collectors is 129128.352 m^2.

KSF Zone - connects Pristina with Fushe Kosova, in this area is Barracks of the Kosovo Security Force, from which it has its name KSF. In this area is also Industrial zone, the town market, part where solar collectors are not recommended. It is very little inhabited, predominantly with individual housing. The appropriate surface for installation of solar collectors is 32249.95 m^2.

Çagllavica - located on the outskirts of the city, is inhabited with individual housing with house distributed. The appropriate surface for installation of solar collectors is 47511.0034 m^2.

Kalabria - has single and multiple residential building. The appropriate surface for installation of solar collectors is 103484.204 m^2.

Kodra e trimave - including a very huge area, in this area mainly have individual housing. The appropriate surface for installation of solar collectors is 305276.95 m^2.

The city center - dominate the high buildings, multiple residential building, this area includes: the Cathedral, National Library, a part of the University Campus, market, where in these areas is not recommended the application of solar collectors. The appropriate surface for installation of solar collectors is 297403.46 m^2.

The total appropriate surface for installation of solar collectors for the Prishtina city is 1781467 m^2.

For all of the selected area it is not necessary to be covered completely with solar collectors [6], knowing that the demand for domestic water depends on the number of inhabitants, institutions (single or multiple residential building, office building, hotel, school, student dormitory, hospital etc) and how much sun its gets based on its geographical location.

3. Hot Water Demand Calculations and Simulation with T*SOL Software

To calculate the demand for sanitary hot water for several different institutions it is necessary to calculate the monthly average radiation incident on the collector, for this is used the method Isotropic Sky [7]. The following table clearly shows that the monthly average radiation incident on the collector is 4.198 (kWh/m^2/day), the maximum value is 5.518 (kWh/m^2/day), in July while the minimum is 2.585 (kWh/m^2/day), is in December Table 3.

Table 3. Monthly and yearly average total radiation on a tilted surface $\bar{H}_T$ (kWh/m^2)

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Anual
Daily	3.031	3.857	4.187	4.299	4.646	5.178	**5.518**	5.467	4.697	3.972	2.937	**2.585**	**4.198**
Monthly	93.96	107.99	129.80	128.97	144.01	155.34	171.06	169.48	140.92	123.13	88.12	80.14	1532.93

The capacity of sunlight is calculated for eight months, since for the other months during the winter, connected the Distring Heating or electricity, which serves for space heating and sanitary hot water.

The average capacity of sunlight for eight months is q=4.746 (*kWh/m²*).

Table 4. Basic data for some institution in Prishtina city

Daily average sanitary hot water consumption [l]	House	Building	Dormitory nr.3	Dormitory nr.8	Regional Institute of Public Health	Infectious Disease Clinic	House	Building	Dormitory nr.3	Dormitory nr.8	Regional Institute of Public Health	Infectious Disease Clinic	House
	200	3600	11200	5400	4000	4000	4000	4000	200	3600	11200	5400	4000
The number of collectors	2	27	72	35	24	24	26	26	2	27	72	35	24

With these data is calculated the daily average sanitary hot water consumption and the number of collectors for some institutions Table 4. Average daily hot water demand in liters per day at 40 to 60°C [8].

For simulation is used T*SOL software, the T*SOL software is the program that allows to accurately calculate the yield of a solar thermal system dynamically over the annual cycle. With T*SOL one can optimally design solar thermal systems, dimension collector arrays and storage tanks, and calculate the economic efficiency [9]. Since SWH cannot meet 100% of the residential apartment's demands or social institutions, there is a need for auxiliary boiler in all stations. In order for the system to function only with renewable energy throughout the year it is connected with district heating in winter season.

Table 5. The results of studied parameters

	Parameters Object	**Solar contribution to DHW (kWh)**		**DHW solar fraction (%)**		**CO_2 emissions avoided (kg)**		**E-SL to tank (kWh)**		**Energy from Auxiliary heating (kWh)**		**Savings District heating (kWh)**	
	Months	**45°C**	**60°C**	**45°C**	**60°C**	**45°C**	**60°C**	**45°C**	**60°C**	**45°C**	**60°C**	**45°C**	**60°C**
House	Jan	133	129	43	30	31	30	137	136	176	305	143	139
	Feb	143	138	51	35	33	32	149	146	137	258	154	149
	Mar	189	189	66	47	44	44	199	199	99	214	203	203
	Apr	205	206	74	53	48	48	216	218	71	180	221	223
	May	202	217	82	62	50	54	220	232	46	134	231	248
	Jun	210	227	87	67	53	57	228	243	31	110	245	266
	Jul	211	245	96	78	53	62	238	265	9.0	68	248	288
	Aug	228	258	98	77	58	65	254	276	5.1	78	268	303
	Sep	201	218	86	66	50	54	221	234	34	113	230	250
	Oct	203	209	79	56	49	50	219	222	55	164	225	231
	Nov	149	145	53	36	35	34	156	154	133	260	161	157
	Dec	107	104	35	24	25	24	111	110	194	325	115	112
	Year	2179	2284	69	51	528	555	2348	2434	990	2209	2444	2568
Multi – family dwelling	Jan	2309	2324	42	30	536	540	2309	2239	3165	5361	2483	2499
	Feb	2510	2544	50	36	583	591	2510	2527	2496	4494	2699	2736
	Mar	3325	3418	66	48	772	794	3325	3431	1731	3659	3576	3675
	Apr	3570	3718	75	55	836	870	3570	3778	1173	2983	3868	4027
	May	3586	3926	85	65	885	970	3586	3981	623	2077	4095	4491
	Jun	3615	4052	90	70	913	1024	3615	4162	403	1699	4226	4740
	Jul	3551	4347	99	84	902	1105	3551	4476	39	823	4178	5114
	Aug	3870	4581	98	80	983	1164	3870	4653	67	1131	4552	5390
	Sep	3469	3858	89	68	857	954	3469	3946	439	1779	3968	4417
	Oct	3575	3810	80	59	855	911	3575	3818	876	2668	3958	4215
	Nov	2666	2671	58	41	623	624	2666	2671	1899	3848	2882	2889
	Dec	1876	1888	35	25	436	438	1876	1864	3495	5757	2017	2030
	Year	37922	41137	70	53	9181	9984	37922	41637	16404	36277	42503	46223
Dormitory nr.8	Jan	2884	2905	42	30	670	675	2922	2930	4055	6826	3102	3124
	Feb	3242	3283	41	29	753	762	3188	3233	4716	7884	3486	3530
	Mar	4121	4245	66	48	957	986	4151	4264	2145	4578	4481	4565
	Apr	4885	4950	57	41	1142	1157	4908	4968	3675	7156	5287	5357
	May	5522	5642	58	41	1365	1395	5556	5670	3960	7992	6320	6459
	Jun	5926	6082	61	43	1497	1537	5977	6120	3778	7992	6932	7115
	Jul	5891	6263	82	60	1497	1592	6078	6410	1277	4200	6931	7368
	Aug	3464	4657	100	95	880	1183	3740	4851	0	220	4075	5478
	Sep	3834	4555	95	79	946	1125	4013	4681	182	1228	4378	5206
	Oct	3453	4770	83	61	1066	1140	4459	4771	929	3001	4935	5279
	Nov	3407	3407	57	39	796	796	3370	3388	2608	5237	3684	3687
	Dec	2305	2320	39	28	535	539	2293	2305	3572	6046	2479	2495
	Year	49933	53079	62	46	12104	12887	50655	53593	30896	62360	56038	59663

Dormitory nr.3	Jan	6074	6102	42	30	1411	1417	6178	6175	8257	13979	6531	6561
	Feb	6796	6853	41	30	1578	1592	6681	6758	9629	16198	7308	7369
	Mar	8657	8920	67	49	2011	2072	8712	8955	4270	9268	9309	9591
	Apr	10544	10746	60	43	2464	2512	10585	10781	7132	14255	11409	11627
	May	12909	12375	62	44	2982	3060	12130	12426	7526	15796	13804	14166
	Jun	10544	13342	64	46	3262	3371	13020	13418	7140	15730	15101	15608
	Jul	12064	13672	86	63	3220	3474	13027	13964	2123	7931	14906	16085
	Aug	7044	9668	100	97	1790	2457	7500	9980	0	305	8287	11374
	Sep	7911	9480	96	80	1952	2340	8198	9659	311	2379	9037	10835
	Oct	9143	9958	83	62	2189	2380	9118	9973	1896	6062	10134	11.20
	Nov	7221	7218	58	41	1687	1686	7123	7161	5164	10578	7808	7808
	Dec	4892	4920	40	29	1136	1143	4871	4892	7236	12333	5260	5290
	Year	105926	113255	64	48	25681	27504	107145	114143	107145	124815	118893	127335
Infectious Disease Clinic- S	Jan	2367	2375	42	30	550	552	2379	2385	3264	5523	2545	2553
	Feb	2653	2668	47	34	616	620	2630	2643	3003	5288	2852	2869
	Mar	3579	3638	62	45	831	845	3592	3644	2192	4476	3849	3912
	Apr	3783	3900	73	53	886	913	3858	3964	1434	3460	4101	4225
	May	3993	4255	80	60	986	1052	4051	4299	998	2892	4564	4869
	Jun	4039	4373	87	66	1020	1105	4183	4477	589	2274	4723	5116
	Jul	4245	4838	97	76	1079	1229	4384	4944	116	1492	4994	5692
	Aug	4153	4781	97	77	1055	1215	4266	4864	107	1416	4886	5625
	Sep	3802	4125	85	64	940	1020	3930	4199	656	2332	4352	4723
	Oct	3886	4049	76	54	929	967	3866	4051	1215	3400	4299	4479
	Nov	2809	2830	51	36	656	661	2803	2822	2714	5059	3038	3062
	Dec	1851	1861	42	30	430	432	1844	1852	2541	4372	1991	2001
	Year	41161	43694	69	51	9978	10611	41787	44145	18829	41983	46193	49125
IKSHP – Solar 1	Jan	2191	2201	40	29	509	511	2333	2341	3281	5464	2355	2366
	Feb	2353	2397	45	33	546	557	2354	2393	2849	4818	2530	2577
	Mar	3413	3462	58	42	793	804	3318	3368	2475	4783	3670	3723
	Apr	3535	3627	65	47	823	844	3600	3686	1942	4120	3811	3909
	May	3693	3862	79	58	910	952	3767	3928	964	2816	4211	4406
	Jun	3768	3991	86	63	949	1006	3885	4083	633	2371	4394	4656
	Jul	3820	4174	93	70	971	1061	4033	4381	282	1815	4494	4911
	Aug	4167	4649	98	75	1059	1181	4193	4647	81	1543	4903	5470
	Sep	3713	3925	83	60	916	968	3801	3995	773	2634	4240	4481
	Oct	3492	3616	71	51	837	866	3666	3792	1416	3480	3857	4011
	Nov	2769	2801	52	37	648	655	2648	2678	2512	4751	2998	3033
	Dec	1879	1897	33	24	436	441	1867	1883	3847	6145	2021	2040
	Year	38793	40601	65	48	9396	9846	39465	41176	21056	44741	43501	45583

As a general conclusion it can be suggested that for sanitary hot water temperature from 45 to 60˚C: the average total solar fraction for Pristine is 58%, the average solar contribution is 605 kWh/m^2, the average CO_2 emissions per panel's meter square is 146 kg/m^2 and total annual savings in CO_2 emissions in total is 69127.5 kg, and the average Savings District heating is 4355.96 kWh.

The results obtained through these models will then be used as arguments for convincing policymakers or decision makers to make important decisions about investing in solar thermal energy in the city of Prishtina or other cities in Kosovo.

4. System Definition

This system providing sanitary hot water for Infectious diseases Clinical. In the first step the roof position for the solar collectors was analysed, after that calculated the most suitable surface area for the solar panels Figure 4 shows a)

The roof of the clinic while under b) the most suitable part for the installation of solar collectors, the figure shows that there is sufficient space for installation the collectors to meet the demand for sanitary hot water for this Clinic.

Based on the daily demand for sanitary hot water it is calculated the number of collectors that will be placed in this clinic. Figure 4 show that the free surface is 373.42 m^2; whereas, according to the calculations before the roof surface that need for installed solar panels is 115.09542 m^2.

Figure 4. Infectious diseases Clinic

After that was description the main components of the solar hot water heating system for the Infectious diseases Clinic are:

Closed-Loop System – The system is designed as a standard closed loop system, where a pump circulates a water/propylene glycol mixture through the collectors and an external heat exchanger.

Infectious Diseases Clinic – A total of nine modules were installed at the Clinic, with two parts:

Solar I of four modules plumbed in series. Two set of seven panels are plumbed in parallel and two modules with six panels also plumbed in parallel.

Solar II of five modules plumbed in series, four set of five panels are plumbed in parallel and one module with six panels.

Preheat Tank – There are two preheat tanks in this clinic (with 2×2000 liters- for two parts), that heated water from the solar thermal collectors and preheat the domestic hot water before it is supplied to the auxiliary tanks. As shown in Figure 5, the preheat tanks are heated solely by the collector array.

Auxiliary Tank – Infectious diseases Clinic system uses a standard Auxiliary Tank with 2000 liter (Type: KODSAN KCD, the diameter 1260 mm and the height 2230 mm [10]). Pre-heated water from the preheat tanks is fed to the auxiliary tank where it is heated to the hot water delivery set point, if necessary, and supplied to the facility. In the winter season this tank heated from District Heating.

External Heat Exchanger – An external heat exchanger transfers heat from the solar collectors to the pre-heat tanks.

Solar Pump Station – Circulation pumps circulate water through the solar thermal loop and the external heat exchanger. A separate set of pumps circulate fluid from the pre-heat tanks to external heat exchangers.

Solar Controller – Under normal operations at the Bean Center, the circulating pumps serving the solar collectors and the solar storage tanks are started when the collector temperature exceeds the solar tank storage, and stopped when the collector temperature is less than the solar storage tank.

Installed Costs – The installed system cost of the 52-panel system at the Infectious diseases Clinic is 41040 € (for both of them Solar I and Solar II). A photo of the 52 - panel divided in tri part, installation at the Infectious Diseases Clinic is provided in Figure 5.

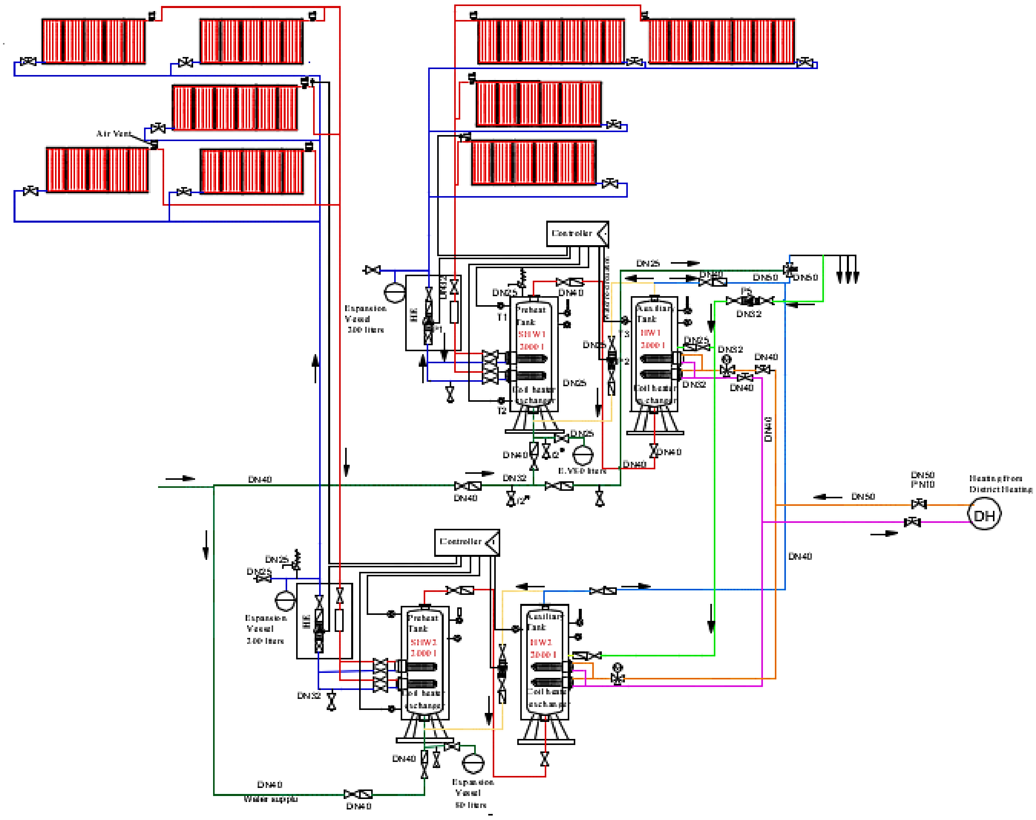
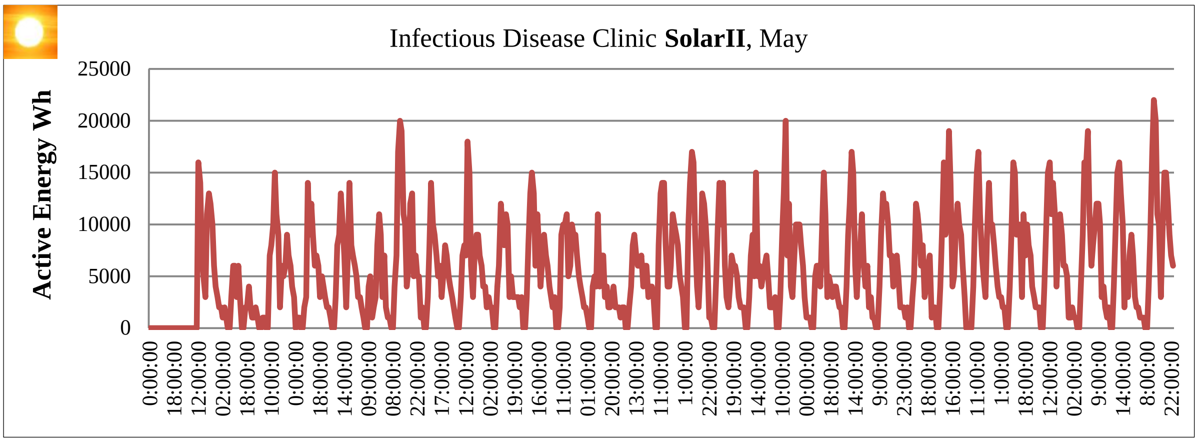
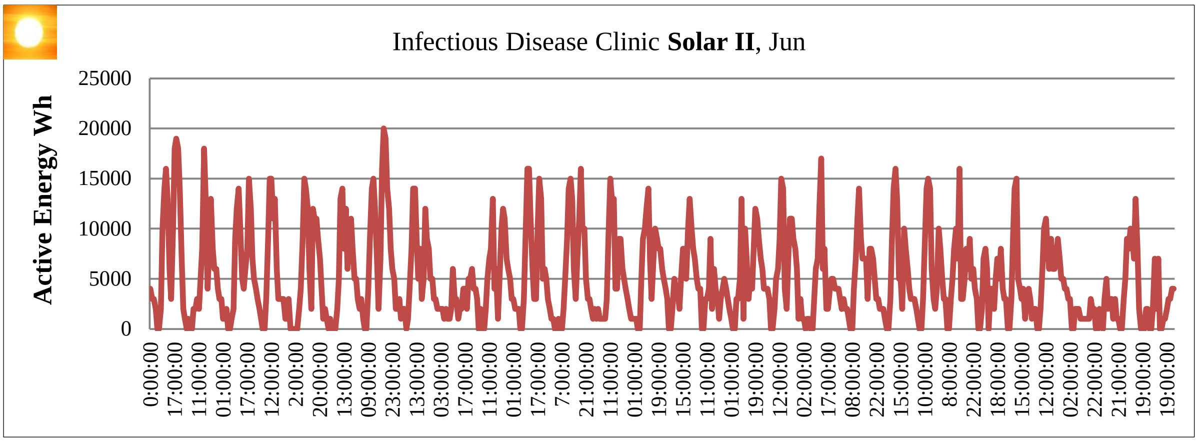


Figure 5. Schematic Solar Hot Water System at the Infectious diseases

To evaluate the active energy of a system for a time period, it is necessary to analyze the daily, monthly and annual performance for that system, data monitoring for station Solar II during the period May - September are presented in the Figure 6.





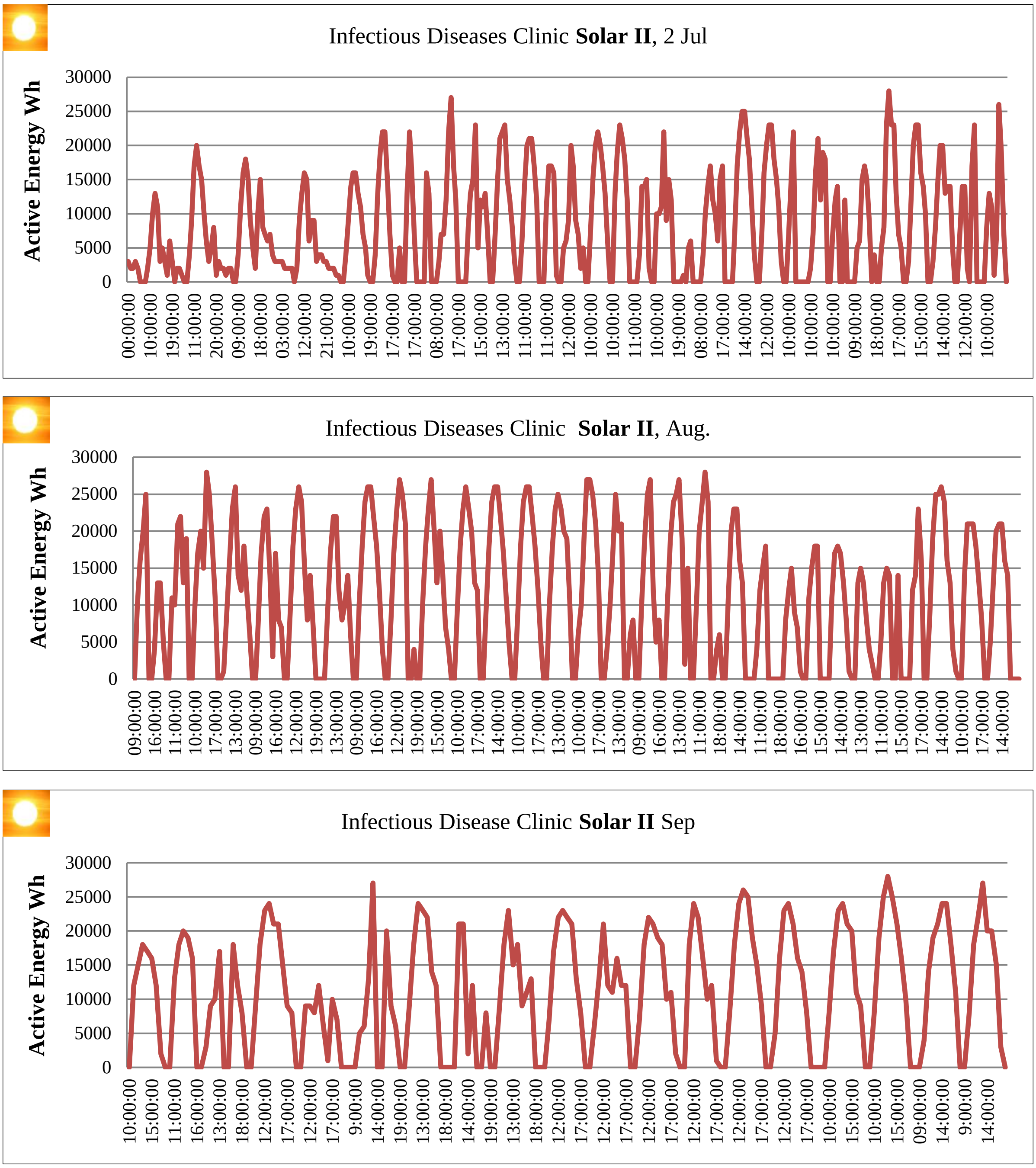


Figure 6. Data monitoring for station Solar II during the period May - September

The maximum value in this station is 1100 (Wh), with 31 July, shows into the Figure 7.

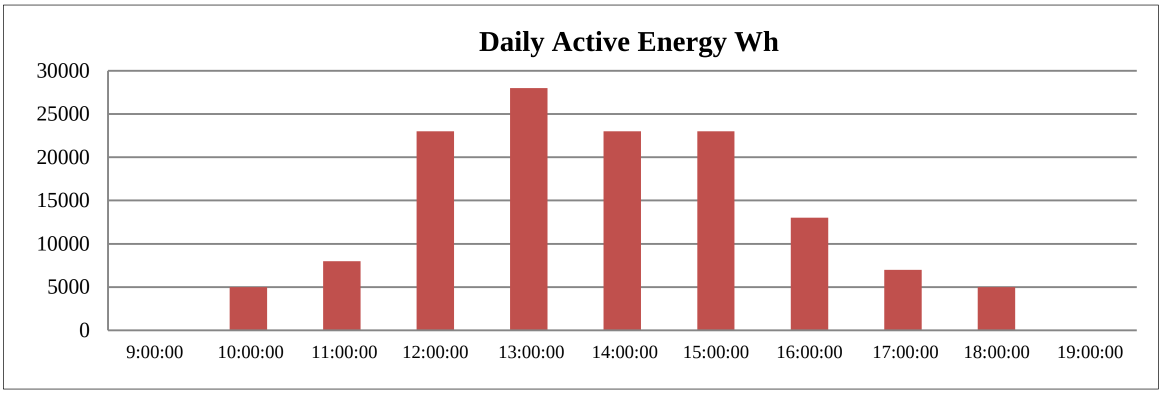


Figure 7. The maximum value in this station (31 July)

5. Mathematical Model

In this part is given the formulation and development of the mathematical model using the F-chart method to estimate the annual thermal performance of active heating systems for building, where the minimum temperature of energy delivery is near 20°C.

It was designed for a standard water heating system, where the conditions of the simulations were varied over appropriate ranges of parameters of the system design. This makes the f-chart method viable for a very limited range of parameters (Collector area, Tank volume, Tilt angle etc.), otherwise the results obtained with the correlations would be wrong.

In order to obtain results for a solar thermal system, the input data is necessary (Location - Pristine, Latitude - $L = 42^o 39' \ N$, Slope - 45°, and other data shown in Table 6). This model is used for Domestic Water Heating.

Table 6. Prishtina's meteorological data

Month	$\bar{H}_T$ (MJ/m^2)	$\bar{K}_T$	ρ_g	Ta (°C)
January	10.911	0.428	0.7	0.20
February	13.885	0.465	0.7	2.57
March	15.074	0.467	0.4	6.60
April	15.476	0.457	0.2	11.15
May	16.724	0.478	0.2	15.64
June	18.642	0.534	0.2	19.72
July	19.865	0.573	0.2	22.21
August	19.682	0.572	0.2	22.15
September	16.91	0.518	0.2	16.32
October	14.299	0.48	0.2	11.54
November	10.575	0.424	0.2	6.26
December	9.306	0.406	0.4	1.2

The two dimensionless groups are:

$$X = F_R \cdot U_L \cdot \frac{F_R^{'}}{F_R} \cdot \left(T_{ref} - T_a\right) \cdot \Delta t \cdot \frac{A_C}{L} \tag{1}$$

$$Y = F_R \cdot \left(\tau\alpha\right)_n \cdot \frac{F_R^{'}}{F_R} \cdot \frac{\overline{\left(\tau\alpha\right)}}{\left(\tau\alpha\right)_n} \cdot \overline{H_T} \cdot N \cdot \frac{A_C}{L} \tag{2}$$

Where:

Ac: Collector area (m^2);

F_R': Collector heat exchanger efficiency factor (%);

F_R: Collector heat removal factor (%);

U_L: Collector overall loss coefficient (W/m^2 ^{o}C);

Δt: Total number of seconds in month;

$\bar{T}_a$: Monthly average ambient temperature (^{o}C);

$T_{ref} = 100\ ^oC$: Empirically derived reference temperature;

L: Monthly total heating load for space heating and hot water (J);

$\bar{H}_T$: Monthly average daily radiation incident on collector surface per unit area (J/m^2);

N: days in month;

$\tau\alpha$: Monthly average transmittance - absorptance product [7, 11].

The overall loss coefficient $F_R U_L$ and the optical performance $F_R(\tau\alpha)_n$ are necessary parameters to insert in the numerical model; however these parameters change depending on the efficiency of the solar collector and on the weather data of the solar system.

The parameters of the collector are as follows:

- Overall loss coefficient $F_R U_L = 6.1\ (W/m^2\ {}^oC)$;
- Optical performance $F_R(\tau\alpha)_n = 0.8277$.

$$\eta = \eta_\circ - a_1 \frac{T_m - T_a}{G} - a_2 \frac{T_m - T_a^2}{G} \tag{3}$$

Where [12]:

$\eta_0 = 0.816$;
$a_1 = 4.096\ (W/m^2K)$;
$a_2 = 0.010\ (W/m^2K^2)$;
T_m: Average collector temperature;
T_a: Ambient temperature;
$G = 800\ W/m^2$.

The Daily Heat load for Infectious Disease Clinic- **Solar I** is 4000 (l/day) as analyzed before.

In F-chart method, the system's performance is expressed in terms of f, which is the fraction of the heating load supplied by solar energy during each month.

$$f = 1.029 \cdot Y - 0.065 \cdot X - 0.245 \cdot Y^2 + 0.0018X^2 + 0.0215Y^3 \tag{4}$$

The fraction of the annual water heating load supplied by solar energy is determined by repeating the calculation of X, Y, and f for each month and summing the results as indicated by Equation 4. The Table 7 shows the results of these calculations.

Table 7. Monthly and Annual Performance for Infectious diseases Clinic

Month	L (GJ)	Xc	Y	f	f_L (GJ)
January	18.09	5.582	0.843	0.399	7.224
February	16.34	5.303	1.072	0.554	9.057
March	18.09	4.806	1.164	0.629	11.38
April	17.51	4.259	1.195	0.672	11.77
May	18.09	3.708	1.292	0.75	13.58
June	17.51	3.213	1.44	0.848	14.84
July	18.09	2.911	1.534	0.906	16.39
August	18.09	2.918	1.52	0.899	16.27
September	17.51	3.626	1.306	0.762	13.34
October	18.09	4.206	1.104	0.625	11.31
November	17.51	4.847	0.817	0.416	7.283
December	18.09	5.461	0.719	0.32	5.786
Annual	213			0.649	138.2

In this part the f-chart numerical model will be used to calculate the monthly absorbed solar energy for the year 2018, these results will be compared to data from the T*SOL software. Weather data, monthly average ambient temperature, monthly solar radiation, monthly clarity index, ground reflectance/absorptance, the overall loss coefficient and optical performance previously calculated were also used in the calculations as well as the daily heat load previous are mentioned before.

Table 8. Monthly and annually data from f-chart model and T*SOL software

	Solar fraction (%)		Solar Contribution (kWh)	
	f-chart	**T*SOL**	**f- chart**	**T*SOL**
Jan	0.399	0.42	2006.66	2367
Feb	0.554	0.47	2515.8	2653
Mar	0.629	0.62	3161.11	3579
Apr	0.672	0.73	3269.4	3783
May	0.75	0.8	3772.22	3993
Jun	0.848	0.87	4122.22	4039
Jul	0.906	0.97	4552.77	4245
Aug	0.899	0.97	4519.44	4153
Sep	0.762	0.85	3705.5	3802
Oct	0.625	0.76	3141.66	3686
Nov	0.416	0.51	2023.056	2809
Dec	0.32	0.42	1607.22	1851
Annual	0.648333	0.699167	38397.06	40960

In the following, an annual overview of the Infectious diseases Clinic was made. Annual solar contribution, money saves and CO_2, reduction were calculated as follows:

- Annual solar contribution data;
- Money saves depend on the fuel, in this case is electricity;
- CO_2 reduction.

Where:

Annual solar contribution f-chart Table 10 kWh;

Boiler efficiency 0.95;

Unit price of electricity 0.69 €/kWh;

CO_2 emission per kWh electric 0.219 kgCO_2/kWh.

Table 9. Monitored Infective disease clinic

	Solar contribution (kWh)	Annual money saves (€)	Annual CO_2 reduction (kg)
Jan	2006.66	145.7469	462.5879
Feb	2515.8	182.7265	579.9581
Mar	3161.11	229.5964	728.719
Apr	3269.4	237.4617	753.6827
May	3772.22	273.9823	869.596
Jun	4122.22	299.4033	950.2802
Jul	4552.77	330.6749	1049.533
Aug	4519.44	328.2541	1041.85
Sep	3705.5	269.1363	854.2153
Oct	3141.66	228.1837	724.2353
Nov	2023.056	146.9378	466.3676
Dec	1607.22	116.7349	370.5065
Annual	38397.06	2788.839	8851.533

The following we can shows the results from monitored for the Infectious diseases Clinic, from 1 May to 20 September, solar contribution 6659 (kWh), annual money saves 483.6537 (€) and annual CO2 reduction 1535.075 (kg).

6. Comparison between Modeled, Simulation and Measured Solar Energy Contribution

Experimental measurements for this system were realized in period from 01 May to 29 September. Since, this time is considered the time with highs potential Table 10. From month October to March during the less sunny seasons have been approximated, no enough solar, the energy is supplied from District heating.

The Table 10 shows the total annual solar contribution that is simulated with T*SOL is 40960 kWh per year, while the solar contribution calculated with mathematical model is 38397.06 kWh per year, but data from measured with less than mathematical model and simulation, 29602 kWh per year. Mathematical model and T*SOL yielded somewhat higher total solar contribution compared to the measurements, which is mainly explained by the lower solar irradiation the measured year compared to the climatic data used in the simulation.

Based on real data from this clinic, is done the model for solar thermal energy for city of Pristine.

Table 10. Solar Contribution (kWh)

Month	Sol II	f- chart	T*SOL
Jan	1506	2006.66	2367
Feb	2015	2515.8	2653
Mar	2661	3161.11	3579
Apr	2769	3269.4	3783
May	3272	3772.22	3993
Jun	3026	4122.22	4039
Jul	2886	4552.77	4245
Aug	3452	4519.44	4153
Sep	2744	3705.5	3802
Oct	2641	3141.66	3686
Nov	1523	2023.056	2809
Dec	1107	1607.22	1851
Total	**29602**	**38397.06**	**40960**

7. The Model for Solar Thermal Energy Case Study City of Prishtina

Participation of energy consumption in household is still dominant - about 41.4% of the total consumption in Kosovo, 15% of this energy used for domestic hot water. This energy demand can be lowered significantly by using improved building construction techniques and utilization of RES-s, especially solar thermal. Replacing the electrical heaters with solar water heaters could also lead to reducing the peak load demands. The use of clean energy in electricity generation will also lead to the reduction of carbon dioxide emission to some extent.

Table 11. The basis data for developed of the model

Parameters	Value
Average number of people per house	5
Daily hot water usage estimate	200 (l/day)
Hot water temperature	50 (ºC)
Boiler efficiency	0.95
Collector slope	45 (º)
Miscellaneous losses of collectors	3 (%)
Operating days per week	7
Solar water heater type	Flat plate collector – Wunder ALS 2510 DRAIN
Total gross surface area:	4.86 (m^2)
Total active solar surface area	4.46 (m^2)
Number of collectors	2
Overall loss coefficient	$F_R U_L = 6.1 \ (W/m^2\ ^oC)$
Optical performance	$F_R(\tau\alpha)_n = 0.8277$
Initial cost	1570 (€)
Unit price of electricity	0.69 (€/kWh)
CO_2 emission per kWh electric	0.219 ($kgCO_2$/kWh)
Life span	20 (Years)
Number of Residential households	38289

The energy model was developed for a typical house in the Pristine City using the T*SOL Software and compared with F-chart method.

This basic scenario considers a typical house with 5 occupants (the average size of the family is 4.8 occupants) situated at the Pristine city baring alone the full initial cost of the SWH purchase and installation. Other scenarios can also be developed for number of Households in the city. Based in data from the Kosovo Agency of Statistics the number of residential households in Pristine is 38289.

The annual solar contribution is estimated to be 68%, for sanitary hot water temperature 50˚C, whereas the annual total load is calculated to be 3802.77 kWh /year and the annual covered load is equal to 2606.38 kWh/ year.

Table 12 shows that the annual solar contribution (based in input data from Table 11) is 2606 kWh, the amount saved by using solar energy for water heating is 189.306 (€). The system reduced CO_2, emission by 600.84 (kg), which is an important amount of reduced CO_2, in the atmosphere.

Table 12. Monitored the house with 5 occupants

	Solar contribution (kWh)	**Annual money saves (€)**	**Annual CO_2 reduction (kg)**
Jan	136	9.886	31.37
Feb	169	12.307	39.06
Mar	213	15.535	49.30
Apr	222	16.14	51.22
May	255	18.561	58.91
Jun	278	20.23	64.22
Jul	306	22.29	70.75
Aug	305	22.15	70.31
Sep	250	18.15	57.63
Oct	213	15.53	49.30
Nov	136	9.88	31.37
Dec	108	7.88	24.97
Annual	2606	189.306	600.84

To calculate the demand for sanitary hot water for the city of Pristine, with the number of inhabitants 210282 [13], was taken the total of residential household in Pristine with around 38289 units, and the average number of people per house 5 occupants. The data for the SWHs for Pristine city is summarized in Table 13. The initial cost of the solar water heater is 1570 (€).The maintenance cost is considered to be 5% of the initial investment.

Table 13. Annual solar contribution for city the Pristine

Parameters	**A house**	**All of residential house**
Solar contribution (kWh)	2606	99781134
Annual money saves (€)	190	7274910
Annual CO_2 reduction (kg)	600	22973400
Capital cost	1570	60113730
Maintenance Cost (€)	78.5	3005687
Collector's number	2	76578
Total active solar surface area (m^2)	4.46	170768.9
Total gross surface area (m^2)	4.86	186084.5

Table 13 shows that the annual solar contribution for city the Pristine is 99781134 kWh, to arrive this request is required to be installed 76578 collectors with total gross surface 186084.5 (based in calculation in chapter three: the appropriate surface for installation of solar collectors for city Pristine is 1781467 m^2, which means that we have enough space). The initial cost of the solar water heater for the city is 60113730 €.The system saves the annual money by 7274910 € and reduced CO_2, emission by 22973400 kg, which is an important amount of reduced CO_2, in the atmosphere. In the following, the result for cumulative cash flow analysis for 20 years was presented [14-19].

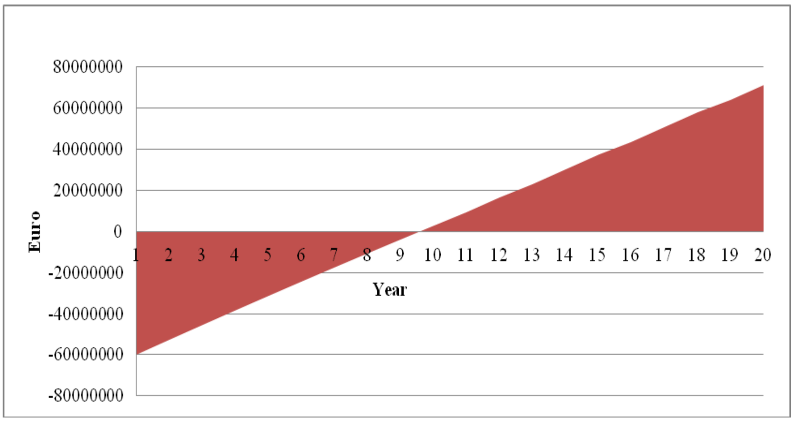


Figure 8. The result of cumulative cash flow analysis for the city of Prishtina

The financial characteristics of the solar water heating system investigated results in savings equal to 71343894 (€) over its life time with a payback period equal to 9.6 years, see Figure 8. These characteristics can motivate the government or municipality of Pristine to invest in solar water heating system since they have a payback period 9 years, they can be easily installed in either flat or slope roof, they have low maintenance cost (approximately 1- 4% of the investment cost) as well as positive net present value.

8. Conclusions

What is the most important conclusion to be drawn from this project?

We know that we didn't solve the mystery of the modest dissemination and implementation of solar thermal. Application of solar thermal energy in Kosovo nowadays is very symbolic. The first solar collectors were installed during 2008-2009.

But we managed to partly widen the system boundaries and method basis in the study of solar thermal especially for domestic hot water, which seems to be a prerequisite to understand the complexity of the dissemination process and identify barriers that tend to appear in the different implementation phases. Based on the result from mathematical model, experimental part, and simulation with T*SOL software, we can conclude that: altogether with a good technological base, creates favorable conditions for the exploitation of solar energy in Kosovo.

Project result overview

The aim of this project was to study a solar domestic water heating system, and replacing the electric water heating system with solar water heating system for city of Prishtina is proposed, to develop a numerical model based on the f-chart method and to compare results obtained from the model with data obtained from T*SOL software and experimental data.

The work starts with an introduction on solar energy, in Kosovo around 93% of the primary energy is provided by fossil fuels, while participation of renewable resources is symbolic. Participation of energy consumption in household is still dominant - about 41.4% of the total consumption in Kosovo, 15% of this energy used for domestic hot water. This energy demand can be lowered significantly by using improved building construction techniques and utilization of RES-s, especially solar thermal.

To provide a more complete support to design the system for city of Prishtina, finance, install and utilize solar energy for sanitary hot water from solar energy, besides other things, are required to possess data with the following information: solar radiation on the optimum horizontal and sloping (tilt) plains for the specific area / location where solar panels will be installed, other climate conditions of the region / location, including average temperatures of air, water, etc.,

Based in Prishtina's meteorological data:

- Prishtina located at coordinates 42°40'0" North and 21°10'0" East;
- The average sun duration for city of Prishtina is 5.44 h;
- The average horizontal irradiation is 3.79 kWh /m²/day;
- The average temperature in July as the hottest month is 19.2°C, while January as the coldest month has a mean value of -1.3°C;
- Annual optimum angle is 33 degree.

To locate suitable locations for the installation of solar collectors serving sanitary hot water, the first step is to divide the city in some areas, and after that, to calculate appropriate roof space the software AutoCAD is used.

- Appropriate surface for the city is 1781467 m^2.

But, for all of the selected area it is not necessary to be covered completely with solar collectors, knowing that the demand for domestic water depends on the number of inhabitants, institutions (single or multiple residential building, office building, hotel, school, student dormitory, hospital etc.) and how much sun is gathered based on its geographical location.

It is clear that the demand for sanitary hot water varies from object to object. In some sectors, sanitary hot water is necessary for example in residential buildings, while in others it increases the quality of life, for example in medical education institutions etc. Another important factor is to calculate monthly and yearly average total radiation on a tilted surface for the city. For this calculation based on the Duffie and Beckman (2013) [7], mathematical software MathCAD has been used:

- The monthly average radiation incident on the collector is 4.198 kWh/m^2/day,

After that, the demand for sanitary hot water for several different institutions has been calculated, in different points of the city: residential house, building, dormitory and two clinics. For these institutions for simulation is used T*SOL software that allows to accurately calculate the yield of a solar thermal system dynamically over the annual cycle.

As a general conclusion it can be suggested that for sanitary hot water temperature from 45 to 60˚C:

- The average total solar fraction for Pristine is 58%;
- The average solar contribution is 605 kWh/m^2;
- The total annual savings for CO_2 emissions is 69127.5 kg;
- The average Savings District heating is 4355.96 kWh.

To analyze in detail the solar contribution, are described data for the main components for three systems,these systems serves for sanitary hot water in two Clinics at The University of Clinical Center of Pristine. For both cases are presented, the monthly analysis starting from May to September month, because this time of period is the time when the solar system reaches the highest energy potential, compared to the other months of the year.

Based on the gained values for Solar Hot Water System at the Infectious diseases Clinic, **Solar I** is seen that the maximum value is around 12-13 o'clock, the highest recorded value is 30000 Wh in July, in this system usually at night from 19 to 9 o'clock there is no energy exchange. After the comparison the data recorded by the controller from Solar station II in Infectious diseases Clinic and the data obtained with the T*SOL Software for daily solar contribution. The analysis shows a slight difference of solar contribution between the values recorded in this station and the values obtained by simulating with TSOL software. The main reason is the weather data for 2018 year, where it is known that this year especially July had lower temperatures compared to what T*SOL receives from Meteonorm software.

The mathematical model also developed for Infectious diseases Clinic - **Solar II** based on the f-chart method by Duffie and Beckman (2013) [7]. For sanitary hot water temperature 45˚C average total solar fraction for this station is 64.9%, the annual solar contribution is 38397.06 kWh. Then the T*SOL software was used to compare data for solar water heating system: between mathematical model and data from software, this difference for solar fraction is 0.05%. Based in the data from mathematical model, for annual solar contribution 38397.06 kWh is calculated:

- The money saved 2788.839 €;
- The CO_2, reduction 8851.533 kg.

Based on the results for annual solar contribution and annual financial savings was reached the result for cumulative cash flow analysis. The simple and equity payback periods are 8.6 years. The investigation for replacing the electrical heaters with solar water heaters for city of Prishtina was based in terms of the electricity cost, capital cost, maintenance cost and the CO_2 emission. The energy model was developed for a typical house with 5 occupants in the Prishtina City using the T*SOL Software and compared with F-chart method. Based on results of the numerical analysis:

- The annual solar contribution for this model is 2606 kWh;
- The amount saved by using solar energy for water heating is 189.306 €;
- The system reduced CO_2, emission by 600.84 kg.

For the life span of the solar water heater 20 years, annual solar contribution 2606 kWh and annual savings of 189.3 € was reached the result for cumulative cash flow analysis, the payback period is equal to 9.6 years. To calculate the demand for sanitary hot water for the city of Prishtina, the total of number of residential households in Pristine with around 38289 units and average number of people per house 5 occupants has been considered.

Based on the calculation the annual solar contribution for city of the Pristine is 99781134 kWh, to cover this request 76578 collectors should be installed. The initial cost of the solar water heater for the city is 60113730 €, the payback period is equal to 9.6 years. The annual savings of the system are 7274910 € and reduced CO_2, emission by 22973400 kg, which is an important amount of reduced CO_2, in the atmosphere. As suggested, if solar water system is to be installed, first step is simulate the system using the software with default conditions. The computing time will be very small, but we will have very accurate data about the solar contribution, solar fraction, CO_2 emissions, financial analysis etc.

The results obtained from this investigate highlight the positive aspects of the use of solar energy to heat domestic sanitary water. On one hand are the environmental aspect, the CO_2 reduction are very important, the use of traditional fossil fuel is avoided, hence the emission of not only carbon dioxide, but also methane nitrous oxide and so on. On the other hand, is the economical aspect, the savings made from the studied solar system are not that high, the payback time is 9.6 year. But Prishtina is ranked among the most polluted sites and this is mainly: by transport, old power plants, and fossil fuel use as a heating fuel for winter seasons.

Therefore, Kosovo needs to look to maximally exploit renewable energy sources for this risen the money saves are not that important, sometimes, in order to get a better environment for our life, the economical profits should be considered as a secondary factor. It is imperative to try and globalize the use of renewable energies for the maximum that we can, using solar energy for sanitary water heating is not a very profitable way but it is surely extremely useful for our environment. The SWHs system is the possible solution because Kosovo struggles to satisfy the energy demands and it is difficult because we have two very older power plants.

9. Conflicts of Interest

The authors declare no conflict of interest.

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