Energy Systems

Solar Thermal Technology

2020/2021

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Introduction

Solar thermal panels use the heat received from the solar radiation which can be used in various ways, such as space heating or water heating. It contains a fluid (can be water or a mix of water and antifreeze) and its function is to absorb said heat and pass it on to the water that is inside the cylinder. This water that will be used for domestic purposes. The most notable advantage this sort of technology has is the significant reduction of carbon emissions during its operation process (carbon mitigation) and the energy independence achieved. However, it also has some negative impacts, which range from minimal ones such as the visual impact, to more serious ones that regard the environment, and have to do with the manufacturing and disposal of the solar panels.

There are several types of collectors, with different efficiency, depending on factors such as solar exposure and temperature difference of the process. To heat sanitary waters, stationary collectors are the most used. Of this type of technology, there are flat without cover, flat with selective cover or vacuum collectors. However, collectors without cover are usually applied in situations that require little energy (such as heating water for a pool), while collectors with a selective cover and vacuum collectors are more flexible, covering a wider range of temperature differences. Since the requirements of the case in study are superior to those covered by collectors without cover, these will not be analysed.

There is also another factor at play, which is the type of circulation system used. The simplest system is the thermosyphon, which uses gravity to circulate the fluid. Since hot water is less dense it will ascend, meaning the cold water will move back down to the collector, creating a natural cycle. It is self-regulating, so it does not consume any extra electricity for pumping and it has no mechanical issues. However, it can have some problems related to the environmental temperatures, since thermal losses (mostly during the night) might cause the mentioned cycle to be reversed. Forced circulation is self-explanatory: the circulation is regulated by a switch that activates a pump anytime the water in the collector is hotter than the water in the deposit. This has additional energy consumption but is more reliable depending on the location. Was decided to assume that all the systems studied used forced circulation.

Initial Data

According to the initial data provided, the island had 50 000 inhabitants, an average of 100 people per square km and around 2,5 people per house. Furthermore, it was considered that the water consumption was 45 liters per person and at 60ºC and that the water temperature for each season was the following:

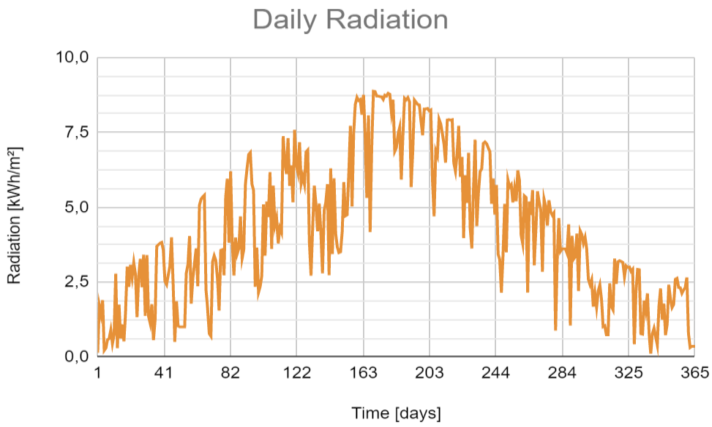
The hourly radiation corresponding to a whole year was also given. With these values the daily radiation of the same year was obtained, which is represented in the following graph:

Season	Temperature [ºC]
Summer	20
Spring/Autumn	15
Winter	10

Table 1 - Water temperature per season.

Development

Starting by selecting a few different panels: two flat collectors with selective covers (to compare possible differences within brand developed technologies) and three vacuum collectors (of which 2 belong to the same brand but have a different number of tubes). In the following table are the characteristics associated with each selected element:



Graph 1 - Daily Radiation for the year.

Panel	Typology	η_p [%]	a_1 [W/m²·K]	a_2 [W/m²·K²]	Area [m²]	Price [€]
1	Flat with selective cover (Brand A)	80,0	3,897	0,015	2,51	732,00
2	Flat with selective cover (Brand B)	76,6	3,216	0,015	2,37	640,00
3	Vacuum tube (15 tubes) (Brand C)	71,5	1,550	0,012	2,47	580,00
4	Vacuum tube (20 tubes) (Brand C)	71,5	1,550	0,012	3,23	680,00
5	Vacuum tube (20 tubes) (Brand D)	73,4	1,529	0,016	3,18	998,15

Table 2 - Panels selected and corresponding characteristics.

With these characteristics one can apply the following equation to calculate the efficiency of each of the selected panels:

$$\eta = \eta_p - a_1 \cdot \frac{\Delta T}{G} - a_2 \cdot \frac{\Delta T^2}{G^2}$$

And having the efficiency of each panel is computed its annual production applying the following equation:

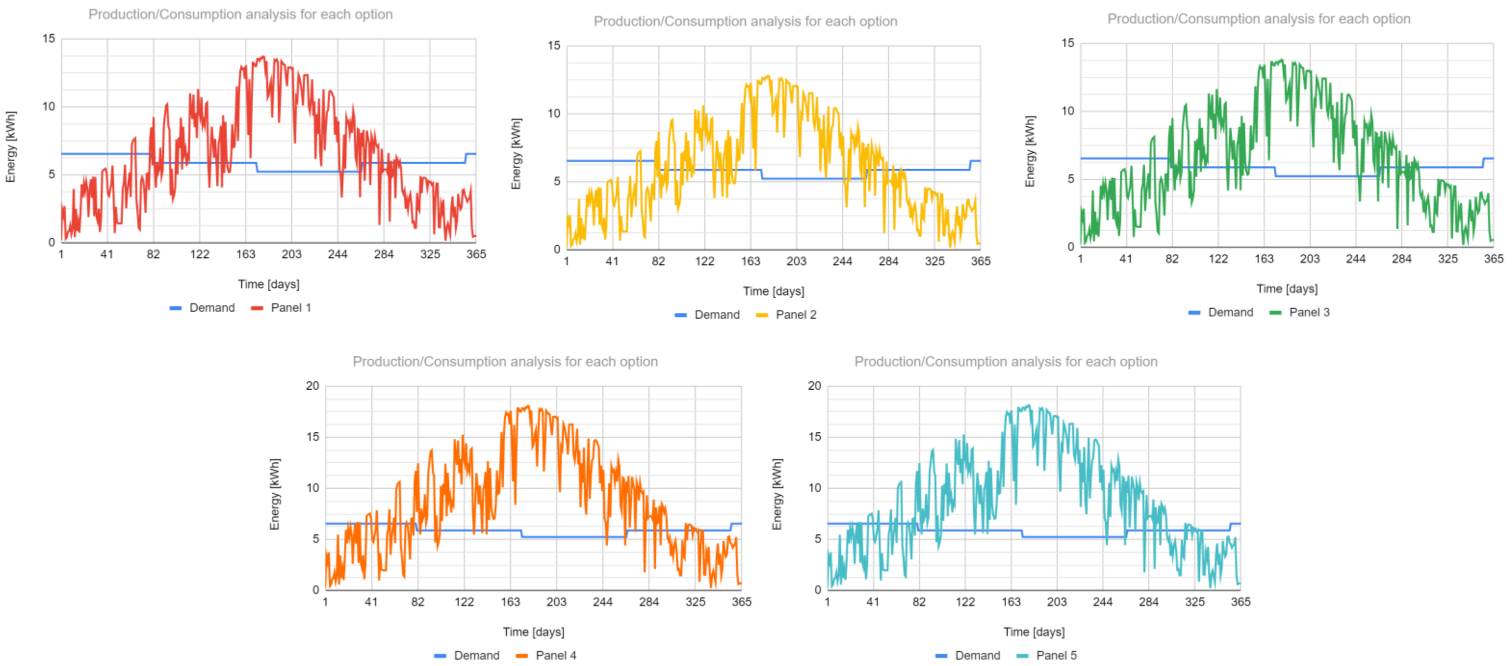
$$Production_{panel} = \Sigma_{year} Radiation_{Sun} \cdot \eta_{panel} \cdot Area_{panel} \cdot Number_{panel}$$

Now, it is required to calculate how much energy is consumed in each house to heat up the 45 liters per person to 60ºC. Since there is an average of 2,5 people in each house, it will have a consumption of 112,5 l per house. So the energy consumption per house will be $Q = C \cdot \Delta T$, where C is the 112,5 multiplied by the specific heat capacity of water, which is 4,1868 kJ/(kg·K) and it's also known that 1 kWh corresponds to 3600 kJ. This process is repeated for the four seasons:

Season	ΔT needed to 60ºC	Q [kJ]	Q [kWh]
Summer	40	18841	5,234
Autumn	45	21196	5,888
Winter	50	23551	6,542
Spring	45	21196	5,888

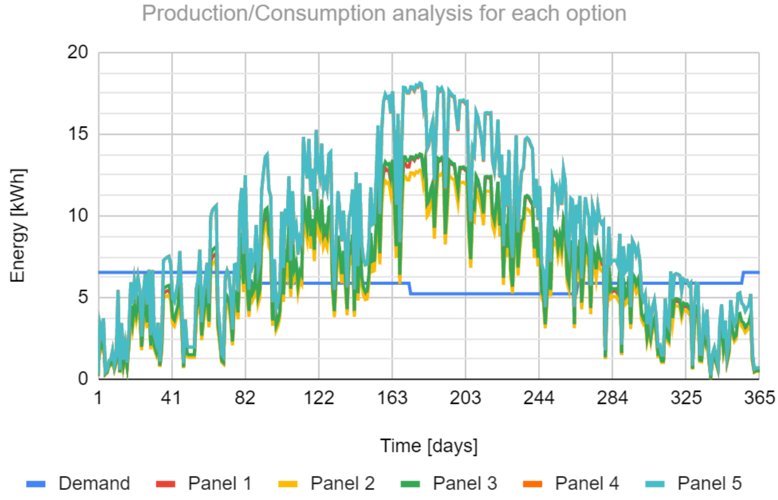
Table 3 - Energy required to cover the water consumption of a house per season.

With this information, we know what the yearly demand is 2148 kWh. Now we must determine how many panels each house should have. We start by analysing the option of having a single panel per house:



Graph 2 - Production and consumption for each panel considering a single panel per house.

Furthermore, the previous data was compiled into the following graph for an easier comparison:



Graph 3 - Production and consumption for all panels considering a single panel per house.

Additionally, were determined: the solar fraction, the percentage of wasted energy and the overall system efficiency of each panel studied, using the following formulas:

$$Solar\ Fraction\ [\%] = \frac{Energy\ Consumed}{Total\ Demand} \times 100$$

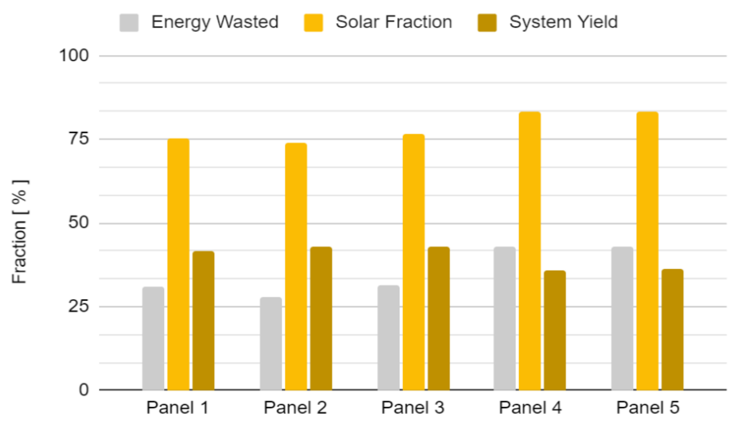
$$Energy\ Wasted\ [\%] = \frac{Energy\ Wasted}{Energy\ Produced} \times 100$$

$$System\ Yield\ [\%] = \frac{Energy\ Consumed}{Annual\ Radiation \times Panel\ Area} \times 100$$

The values obtained are presented in the graph below:

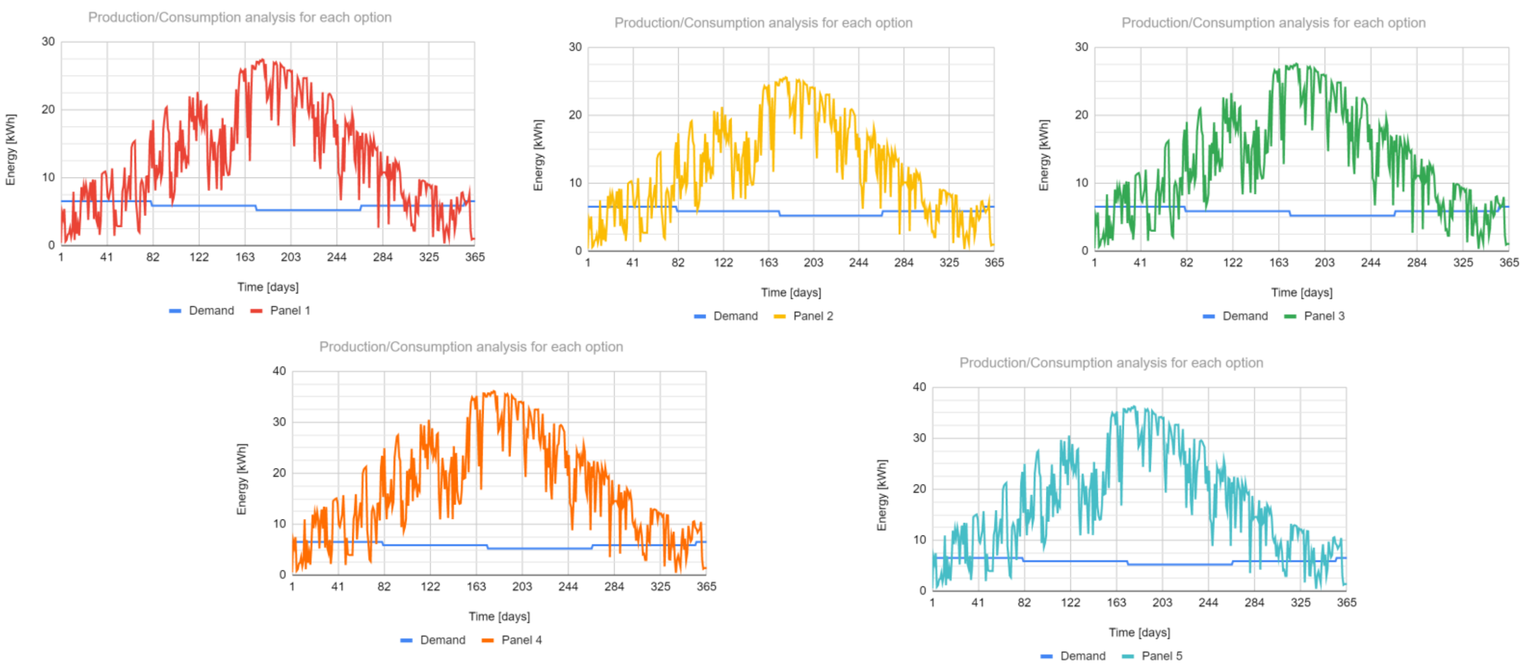
Option	Production [kWh/m²]
Panel 1	933
Panel 2	926
Panel 3	970
Panel 4	970
Panel 5	**988**

Table 4 - Production for each panel.



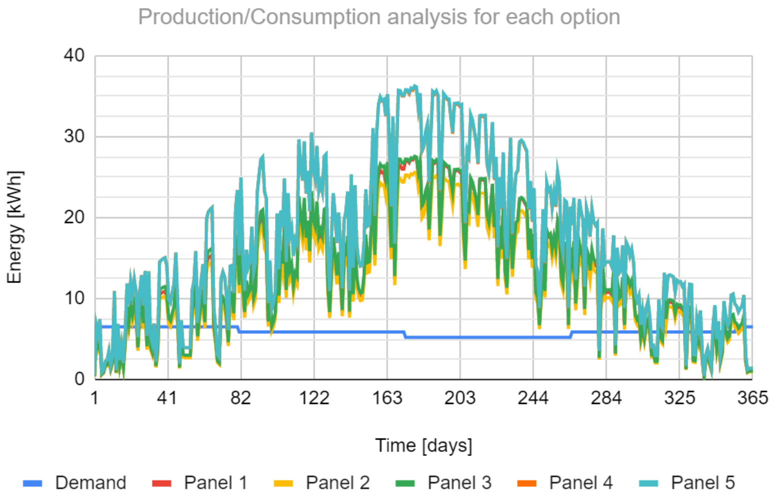
Graph 4 - Wasted energy, solar fraction and system yield for each panel considering a single panel per house.

We then repeated the same process for 2 panels per house:



Graph 5 - Production and consumption for each panel considering two panels per house.

Once again these values were compiled into a single graph for comparison:

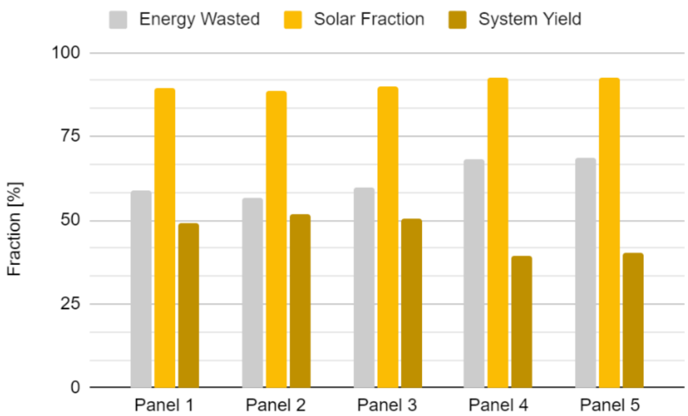


Graph 6 - Production and consumption for all panels considering two panels per house.

Was also determined the energy wasted, solar fraction and system yield:

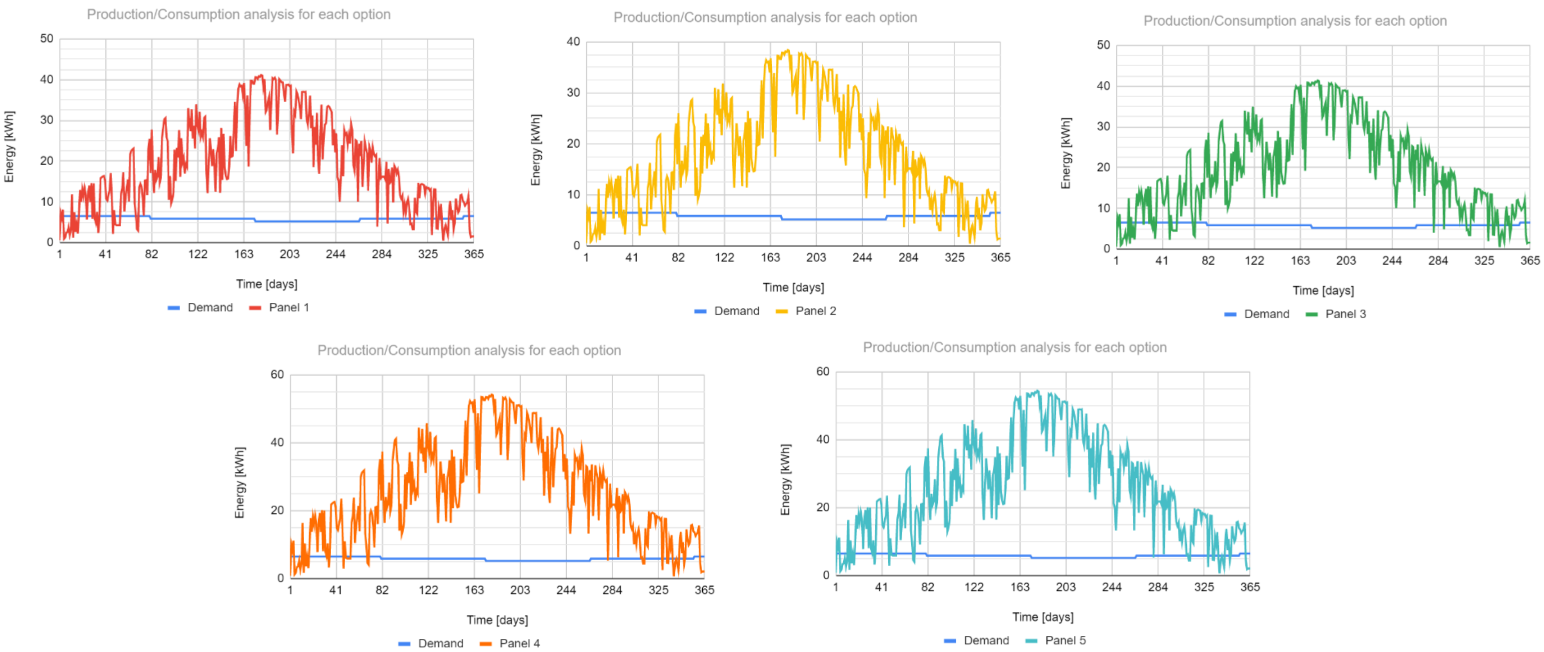
Option	Production [kWh/m²]
Panel 1	1 865
Panel 2	1 852
Panel 3	1 939
Panel 4	1 939
Panel 5	1 975

Table 5 - Production per panel.

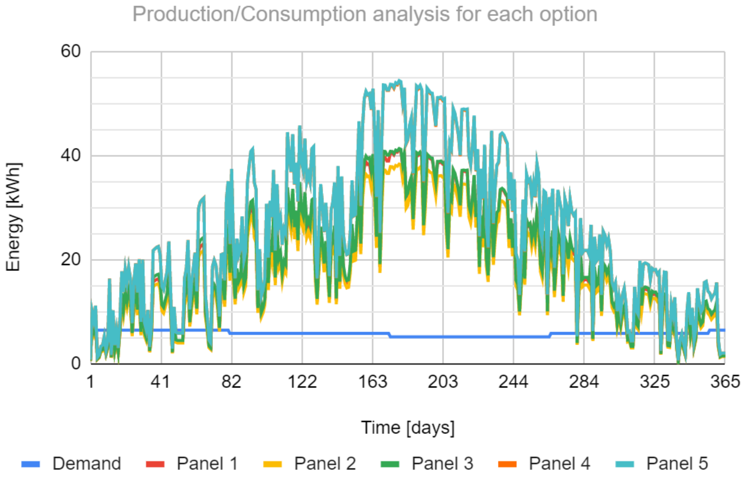


Graph 7 - Wasted energy, solar fraction and system yield for each panel considering two panels per house.

The same process was once again repeated, for three panels.



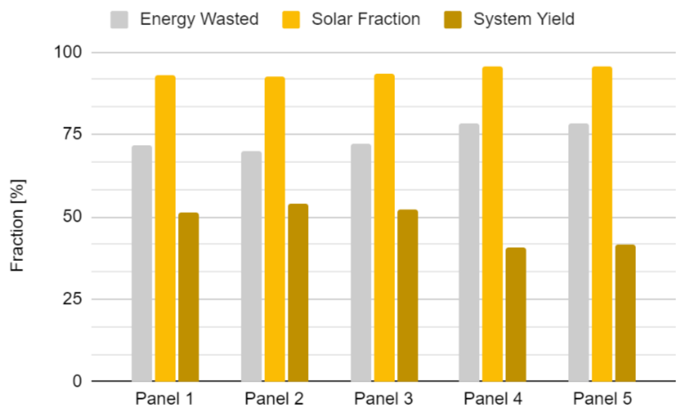
Graph 8 - Production and consumption for each panel considering three panels per house.



Graph 9 - Production and consumption for all panels considering three panels per house.

Option	Production [kWh/m²]
Panel 1	2 798
Panel 2	2 778
Panel 3	2 909
Panel 4	2 909
Panel 5	2 963

Table 6 - Production per panel.



Graph 10 - Wasted energy, solar fraction and system yield for each panel considering three panels per house.

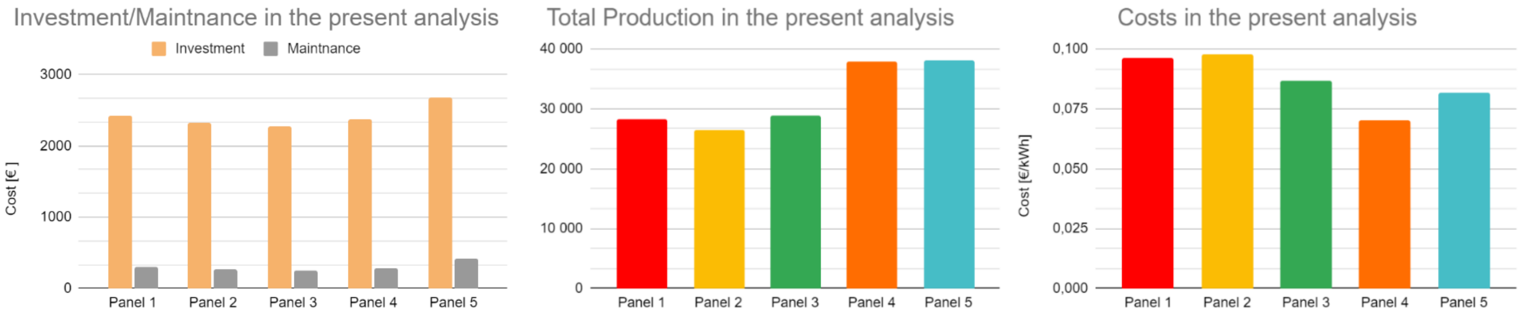
Finally, an economic analysis of each option was done. Was considered a discount rate of 5% and a lifetime of 20 years, according to the bibliography consulted. In addition, was assumed a yearly maintenance cost of 3,5% of the initial cost, as well as an average installation cost of 1686€. The formulas used for a present analysis were:

$$Cost\left[\frac{€}{kWh}\right] = \frac{Total\ Investment}{Total\ Production}$$

$$Total\ Investment\ [€] = Install\ cost + N \times panel\ price + [1 + \%Maintnance \times \frac{(1+d)^{Y-1}-1}{d\times(1+d)^{Y-1}-1}]$$

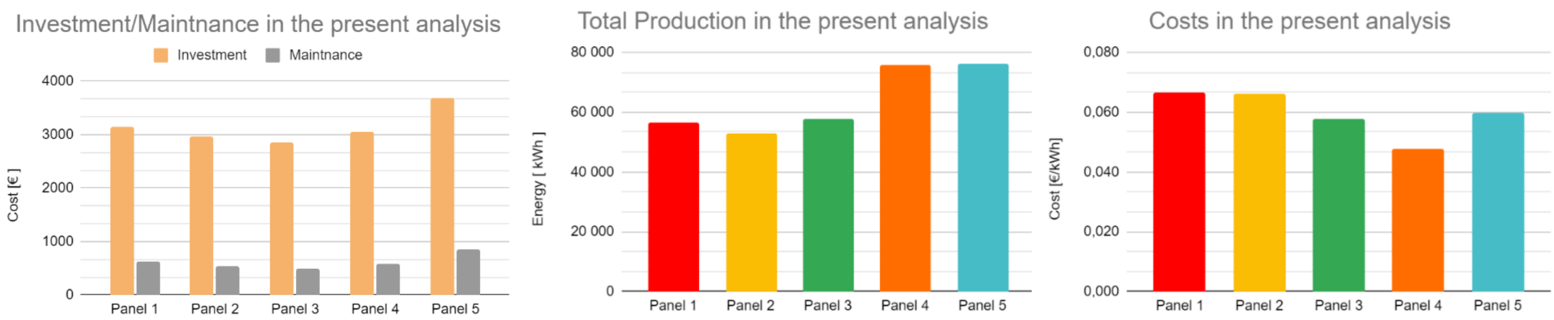
$$Total\ Production\ [kWh] = Energy\ Production \times \frac{(1+d)^{Y-1}-1}{d\times(1+d)^{Y-1}-1}$$

For a single panel, were gathered the following results:



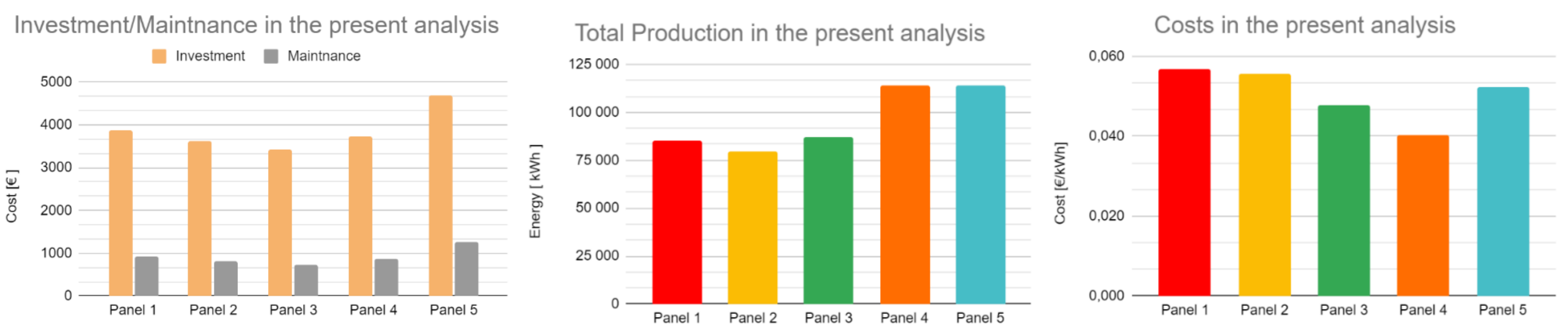
Graph 11 - Present economic analysis for a single panel per house.

For 2 panels per house:



Graph 12 - Present analysis for two panels per house.

And with 3 panels per house:



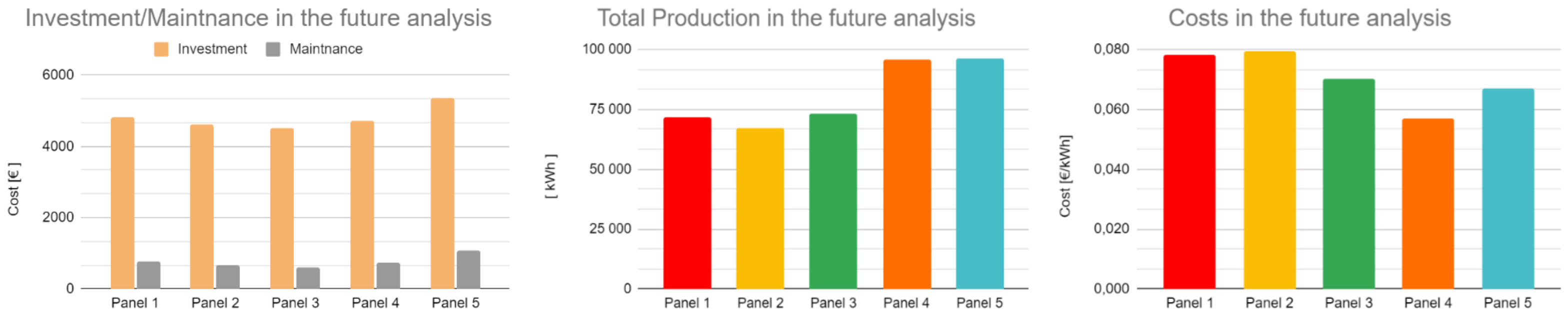
Graph 13 - Present analysis for three panels per house.

In the future analysis the formulas applied were:

$$Total\ Investment\ [€] = Install\ cost \times (1+d)^Y + N \times panel\ price \times \left[(1+d)^Y + \%Maintnance \times \frac{(1+d)^{Y-1}-1}{d}\right]$$

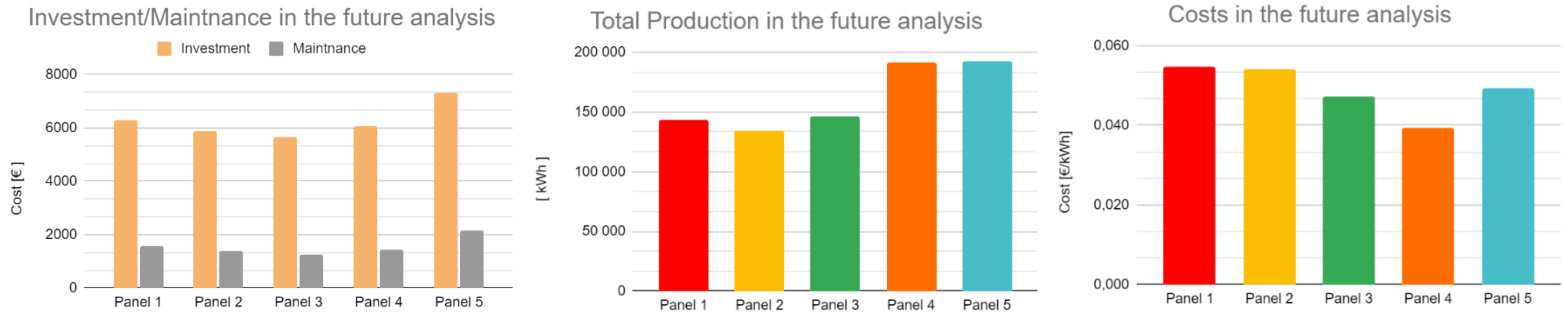
$$Total\ Production\ [kWh] = Energy\ Production \times \frac{(1+d)^{Y-1}-1}{d}$$

For 1 panel per house:



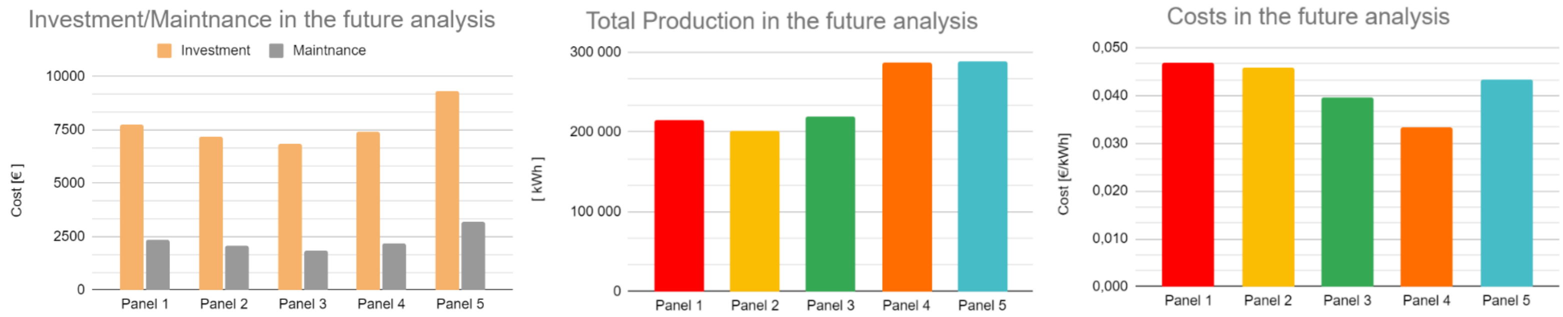
Graph 14 - Future analysis for a single panel per house

With 2 panels per house:



Graph 15 - Future analysis for two panels per house.

For 3 panels per house:



Graph 16 - Future analysis for three panels per house.

Discussion

For the optimization of the system, a few factors were considered: overall investment, solar efficiency and longevity. For the longevity, it was considered that there might be a population growth in the island and as such, it would be useful to have a margin of production to cover this increase in consumption, avoiding a new investment on solar panels if possible. The solar efficiency is self-explanatory, the more efficient this system is, the more useful this option will be. As for the overall investment, it should be as low as it can be, without compromising the other factors.

Panel 4 characteristics	
Investment	3 046 €
Annual Production	6 271 kWh
Solar Fraction	92,4%

After studying all the factors, it was concluded that the optimal choice in the case at study would be for each house to have two vacuum tube panels of Brand C, with 20 tubes (option 4).

Bibliography

[1] T. Tsoutsos, N. Frantzeskaki, and V. Gekas, ‘Environmental impacts from the solar energy technologies’, *Energy Policy*, vol. 33, no. 3, pp. 289–296, Feb. 2005, doi: 10.1016/S0301-4215(03)00241-6.

[2] A. D. de S. Santos, ‘Avaliação de Sistemas Solares Térmicos de Produção de Água Quente Sanitária em Edifícios de Habitação Multifamilia’, Instituto Superior Técnico, Lisboa, 2012.

[3] M. A. C. Miranda, ‘Optimização de Sistemas Solares Térmicos’, Faculdade de Engenharia da Universidade do Porto, Porto, 2008.

[4] P. Nuno, A. Duarte, and A. Francisco De Almeida, ‘Colectores Solares Térmicos-Análise de desempenho térmico de soluções tecnológicas no mercado’, 2012.

Attachments

Option	Production [kWh]	Energy Wasted [kWh]	Energy Consumed [kWh]
Panel 1	2 341	720	1 621
Panel 2	2 194	**611**	1 584
Panel 3	2 395	751	1 644
Panel 4	3 136	1 347	**1 788**
Panel 5	**3 143**	1 355	**1 788**

Table 7 - Production, energy wasted and consumed for a single panel per house.

Option	Production [kWh]	Energy Wasted [kWh]	Energy Consumed [kWh]
Panel 1	4 681	2 762	1 920
Panel 2	4 389	**2 484**	1 904
Panel 3	4 789	2 860	1 929
Panel 4	6 271	4 288	**1 984**
Panel 5	**6 286**	4 303	**1 984**

Table 8 - Production, energy wasted and consumed for two panels per house.

Option	Production [kWh]	Energy Wasted [kWh]	Energy Consumed [kWh]
Panel 1	7 022	5 022	1 999
Panel 2	6 583	**4 594**	1 989
Panel 3	7 184	5 177	2 007
Panel 4	9 407	7 357	**2 050**
Panel 5	**9 430**	7 379	**2 050**

Table 9 - Production, energy wasted and consumed for three panels per house.