INSTITUT NATIONAL DES SCIENCES APPLIQUÉES ROUEN

Physics Project P6

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Solar energy potential for heating a household in Rouen

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Project aims :

Our project's purpose was to look into the potential that the sun's energy could have to heat a household in Rouen. We also wanted to broaden our research on the sun's energy in general, not only the heating. Therefore, our goal was to get an idea of if it would be possible/useful to use different types of solar energy devices in the house.

Project keywords : ***Research, Solar, Rouen, Energy***

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1. Introduction

Energy is the material foundation of human social activities. The development and utilization of new energy is the consensus of mankind. For a long time, people have been trying to study the utilization of solar energy. The solar energy received by our earth is only about one-twentieth billionth of the total energy emitted from the surface of the sun, which is equivalent to 30,000 to 40,000 times the total energy required by the world, which can be described as inexhaustible. The development and utilization of solar energy will not cause air pollution and will not affect the ecological balance of nature. As a renewable energy source, solar energy has attracted more and more attention due to its advantages of longevity, reproducibility and non-polluting. At the same time, conventional energy in the world is gradually decreasing. However, the world population is increasing year by year. With the rapid development of science and technology, it is foreseeable that solar energy will become a more important power source. The development and utilization of solar energy is the long-term pursuit of human society.

The practical application of solar energy to people's homes and daily life has become an important practical problem. On top of the heating aspect of solar energy, we wanted to go around every use of solar energy that is possible. This study will introduce a variety of solar energy utilization methods, including photovoltaic and integrated solar power generation methods, utilization and advantages and disadvantages, the current solar energy utilization cases in France and development status, and a model analysis of the full application of solar energy in an actual household. In a practical case, we combine photovoltaic panels and solar radiators, and focus on their costs and compare them to traditional electricity costs.

2. Methodology / Work organization

For the first weeks, we worked in two teams of two, the first one (Yantian Zhang and Liuxin Yang), was instructed to do some research on photovoltaic solar energy while the second one (Manuel Poullain and Marie-Pascale Tchiakpe) did some research about the non-electric use of solar energy.

The next step was to focus our work in France. We kept our different subjects and groups and we searched how they were applied in France.

After that, we started working on the application to the house in Darnetal. We started to communicate a lot more together, we talked during Zoom video calls, sent messages during the extra hours to divide the tasks and advance more efficiently.

Each week, after we had done our research at home, from the first session to the very last, we would each present our results in front of Mr ALAMIAN. It really helped us prepare for the presentation because some of us weren't really comfortable when it came to presenting their work orally, especially since english is not our first language.

Finally, we finished our assessment and we wrote the report all together.

3. Work carried out and results

Solar energy can be used in many areas and thus offers great opportunities for cooking, heating and, of course, for electricity generation.We propose to study these different uses and their application to a specific house in Darnetal (Normandy).

3.1 Non-electric use of solar energy

3.1.1 Solar ovens

3.1.1.1 Definition of a solar oven

In short, a solar oven is an appliance designed to use solar energy in order to heat a specific point (the focus) or small area at high temperature. I would like to stress that it is a French innovation.

Even if different types of solar ovens exist, the main principle stays the same : The sun beams are concentrated onto one point named the focus where the sun's energy by square meter is then multiplied. The main use of this energy is for cooking and melting. On the one hand, if the energy is concentrated onto one point, the solar oven is set up to melt. But on the other hand if the focus is not placed where the energy is used, then the beams are in an optimal configuration for cooking. These two drawings will help to understand :

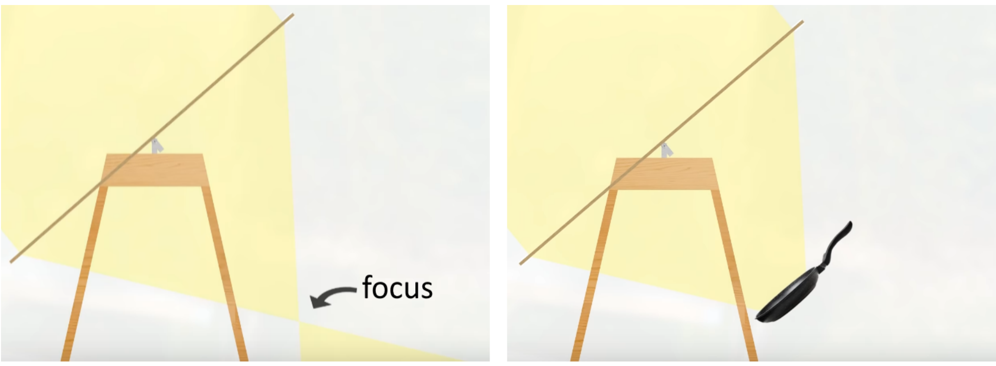


Figure 1 : Different placement for cooking (Fresnel lens oven) (edited) [1]

The advantage of such a device is that it doesn't use electricity nor any fossil fuels therefore slowing down global warming. However, we should not forget that its power will vary depending on the region where it is installed and of course the actual sun exposure which obviously is null at night.

3.1.1.2 The different types of solar ovens

Actually, quite a lot of different types of solar ovens exist.

The most common one is the parabolic solar oven which work with a parabolic mirror that concentrate the sun beams as you can see on this scheme :

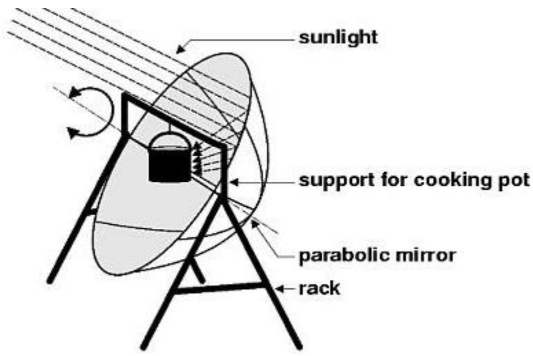


Figure 2 : Parabolic solar oven principle [2]

Another type of solar oven which is less costly but with almost the same efficiency is the Lytefire (or Fresnel mirror solar concentrator). Its principle is actually the same as the parabolic one except that it works with Fresnel mirrors. These ones are based on the Fresnel lens. The mirrors are plain and therefore cost less to produce. This type of solar oven is actually used a lot for professional activities, for example in bakeries or even restaurants.

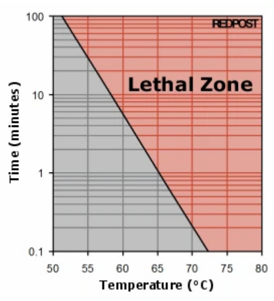
On top of these two, there exist other types of solar ovens that are less used such as the Fresnel lens, the cube/tube cooker or even with a tire using the greenhouse effect.

3.1.2 Solar water purification systems

3.1.2.1 The ways of purifying water

There exist 2 ways of purifying water using solar energy : water distillation and water pasteurization. The difference between the two is that water distillation works thanks to the evaporation of water whereas water pasteurization doesn't need the water to evaporate. Indeed, you'll be surprised to hear that reaching a certain temperature is sufficient to make the water drinkable.

These two techniques have some advantages and drawbacks that I will explain now. The advantage of using the first technique is that any form of water can be purified : Salt water, muddy water, etc whereas the second technique can't make drinkable water that contains salt or that needs to be filtered. However, since the second technique doesn't require the water to evaporate, it is therefore faster and uses less solar energy to operate. Indeed, when we compare the time used by the distillation (that uses condensation like on windows, with water evaporation at 100°C) and pasteurization that can be seen on the graph below, we can notice that the difference is enormous :



Microbe	Killed Rapidly At
Worms, Protozoa cysts *(Giardia, Cryptosporidium, Entamoeba)*	55 °C (131 °F)
Bacteria *(V. cholerae, E. coli, Shigella, Salmonella typhi)*, Rotavirus	60 °C (140 °F)
Hepatitis A virus	65 °C (149 °F)
(Significant inactivation of these microbes actually starts at about 5 °C (41 °F) below these temperatures, although it may take a couple of minutes at the lower temperature to obtain 90 percent inactivation.)	

Figure 3 & 4: Pasteurisation data [3],[4]

3.1.2.2 The different types of water distillation systems

Even if the pasteurization is faster, distillation is actually the dominant solution to purify water, that's why I will only discuss this type of purification. Let me go over the different types of water distillation systems then.

First, we can talk about the Eliodomestico Solar Still by Gabriele Diamanti. This solar still is made up of pottery so it can be constructed easily in hot regions like Africa. The particularity of this one is that it was designed to help people in need of water in drought regions. That's why its style is pretty rustic as shown below. Now as for the working process of this still.

Figure 5 : Eliodomestico solar still picture & pattern [5]

As you can see on the right figure above, the casing consists of two main parts : the salt water storage on top and the clean drinkable water storage in the bottom. When water is poured on top and that metal cap is put back on, the sun will heat the top part and make the salt water be evaporated along the top of the cap and then make it go through a little pipe where it is then condensed into liquid drinkable water.

This system can produce 5 liters of drinkable water per day.

Now let's continue with the SunDwater distillation system. This one can produce up to 250 liters of water every 10 hours of sun making it the most productive one. It consists of a 4 meter parabolic solar reflector which works like a solar oven. However, compared to the previous system, this one is a lot less easy to install since it is big and requires a bit of electricity (a solar panel is present on it) in order to rotate the parabola in front of the sun. However the company closed now.

The next still is a very cheap one which is named the Watercone :

Figure 6: Watercone distillation process [6]

Its principle of working is shown above. You place 1.5 liters of contaminated water on the black plastic disk. Then you put the cone on top of and let the distillation process take over. At the end of the day you can get back your 1.5 L of water cleaned and ready to drink. The advantage of this system is that it is mobile and very cheap. However, it doesn't produce very much so it would not be convenient for more than one person.

The last system that I want to present is the Helios french distillation system. This one works with big bubbles that are filled with salt water on their bottom using a pump (and therefore little electricity). Then the same system of evaporation and condensation is used to collect water flowing on the edges of the bubbles. We will cover the details of this device later.

3.1.3 Solar dryer

A solar dryer is used to keep the food (crops, vegetables, fruits) longer by dehydrating it, using the sun's power, while ensuring good hygienic conditions (protecting the food from insects or dust).

3.1.3.1 The direct solar dryer

The direct solar dryer consists of a frame painted in black most of the time, closed by a glass or plastic plate and the greenhouse effect eliminates the moisture content of the food. To prevent condensation, the frame usually has some holes to allow the circulation of air.

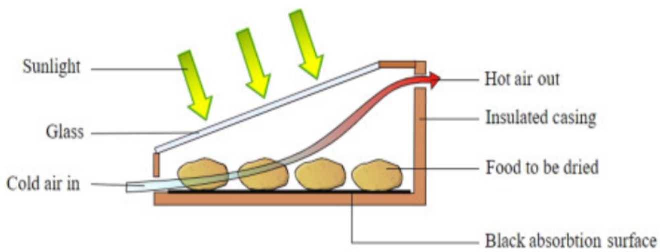


Figure 7 : A Direct Solar dryer [7]

3.1.3.2 The indirect solar dryer

An indirect solar dryer involves circulating hot air between the foods in a frame. The hot air enters through the lower part, heats the food arranged on the grids and is evacuated through the upper part. The frame is surmounted by a glass or Plexiglas plate inclined at 45°, in order to ensure maximum exposure to the sun, with a black plate (absorbing heat) allowing the air to rise towards the food.

There's an example of an indirect solar dryer.

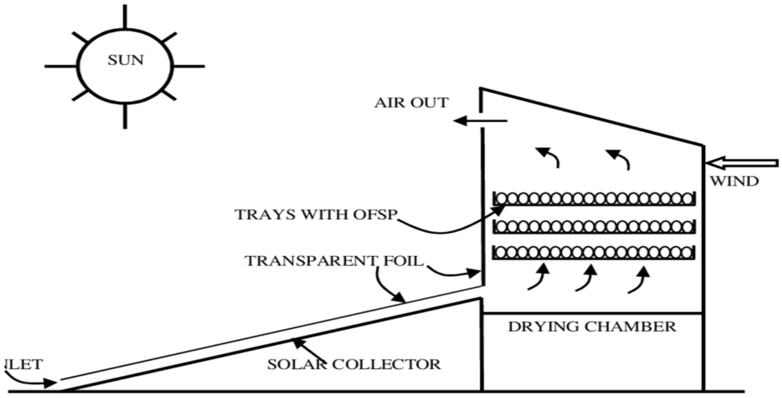


Figure 8 : An indirect solar dryer [8]

3.1.3.3. Advantages and Disadvantages

The main advantage of the solar dryer is that it is ecological because it only uses the sun's power.

On the other hand, a solar dryer is more expensive than a dehydrator. While some dehydrators can be found at less than 70€ (a dehydrator of a 13.5 liters capacity reference of the product 2LACO0231), a solar dryer that would dry up to 3kg of fruit a day would cost at least 175€.

3.1.4. Trombe Wall

A Trombe wall or solar wall is a massive equator-facing wall (typically in concrete or brick) that is painted a dark color in order to absorb thermal energy from incident sunlight and covered with a glass on the outside with an insulating air-gap between the wall and the glaze.

3.1.4.1. How the Trombe wall works

Trombe wall is a passive solar-heating system where the thermal energy flows in the system by natural means such as radiation, conduction, and natural convection. As a consequence, the wall works by absorbing sunlight on its outer face and then transferring this heat through the wall by conduction. Heat conducted through the wall is then distributed to the living space by radiation, and to some degree by convection, from the wall's inner surface.

The greenhouse effect helps this system by trapping the solar radiation between the glazing and the thermal mass.

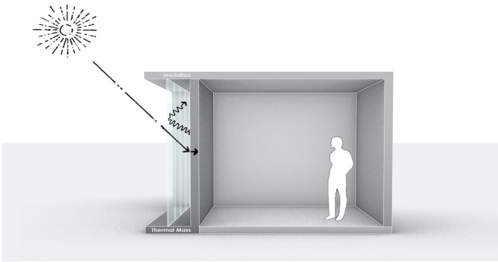


Figure 9 : The Trombe wall collects heat during the day [9]

Another phenomenon that plays a role in the Trombe wall's operation is the time lag caused by the heat capacity of the materials. Since Trombe walls are quite thick and made of high heat capacity materials, the heat-flow from the warmer outer surface to inner surface is slower than other materials with less heat capacity. This delayed heat-flow phenomenon is known as time lag and it causes the heat gained during the day to reach the interior surface of the thermal mass later. This property of the mass helps to heat the living space in the evenings as well. So, if there is enough mass, the wall can act as a radiant heater all night long. On the other hand, the mass shouldn't be too thick, otherwise the living space won't receive enough heat during the evening.

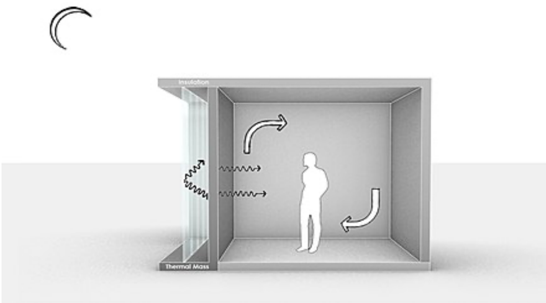


Figure 10: Heat release at night by the Trombe Wall [10]

3.1.4.3.Advantages and Disadvantages

Advantages

- Among the passive solar heating strategies, Trombe walls can harmonize the relationship between humans and the natural environment and are widely used because of advantages such as simple configuration, high efficiency, zero running cost and so on.
- While passive solar techniques can reduce annual heating demand up to 25%, specifically using a Trombe wall in a building can reduce a building's energy consumption up to 30% in addition to being environmentally friendly.
- Glare, ultraviolet degradation, or reduction of night time privacy are not problems with a full-height Trombe wall system.

Disadvantages

- Since the Trombe wall is consolidated in one building element - only the equator-facing facade - its impact on the overall building design is limited when compared to roof ponds or direct-gain systems.

- Natural daylight is lost in the full-height Trombe walls unless the system is combined with a direct-gain system or windows are introduced.
- It is a very climate-dependent system and external temperature and incident solar radiation levels have a significant role in the energy savings and CO2 emission reductions of Trombe walls.
- The system requires user action to operate movable insulation or shutters, often on a daily basis.

3.1.5 Solar water heaters and collectors

To provide heat to a house, we can use solar water heaters or solar collectors. The difference between the two can be hard to see at first.

On the one hand, a solar thermal collector is a device that often looks like a solar panel and that uses the irradiance of the sun to heat a liquid inside it using an absorber plate. It should be stressed that the liquid inside it is not obligatory water.

It exists three types of collectors :

- unglazed plan collector
- glazed plan collector
- evacuated tube solar collector

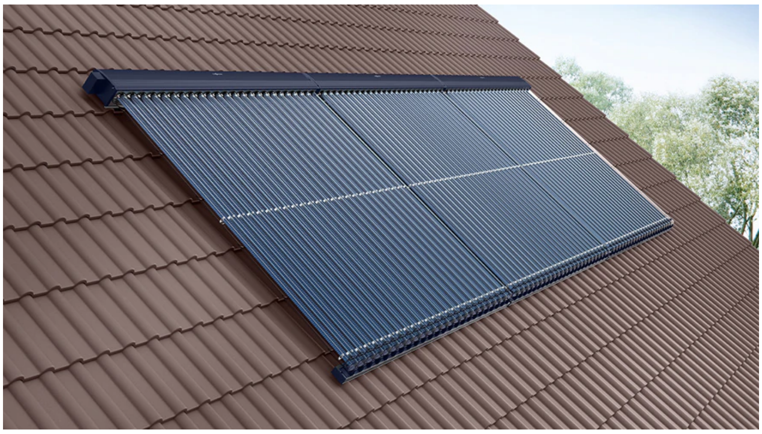


Figure 11 : an evacuated tube solar collector [11]

The one that is the most used is the glazed plan collector that we will use for the house. The unglazed collectors are used more in locations like Africa where the sun's irradiance is very powerful to avoid reaching the overheat of the collector. The evacuated tube collectors are used to reach higher temperatures than the plan ones but are more expensive, fragile and actually less efficient since the surface area of the collector is shorter than the others.

On the other hand, a solar water heater is a system that regroups at the same time a solar collector and a tank.

Figure 12 : A water heater [12]

The trap resides in the fact that if you buy a water heater you buy the whole system of water heating from one company whereas if you buy the collector, the pump, the pipes and the tank apart, you have better control on your project and at the end it also costs less.

3.2 Photovoltaic solar energy

3.2.1 The basic working principle of photovoltaic solar energy

A silicon solar cell uses two different layers of silicon. N type silicon has extra electrons and P type silicon has extra spaces for electrons called holes. Where the two types of silicon meet, electrons can wander across P/N junctions, leaving a positive charge on one side and creating a negative charge on the other. Because of the electric field at the P/N junction, they will only go one way. The electron is drawn to the N-side, while the hole is drawn to the P-side.

The mobile electrons are collected by thin metal fingers at the top of the cell. From there, they flow through an external circuit, doing electrical work like powering a lightbulb, before returning through the conductive aluminum sheet on the back.

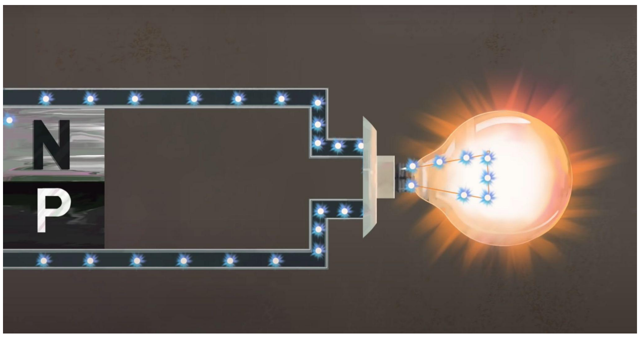


Figure 13 : How PV cells produce electricity [13]

Electrons are the only moving parts in a solar cell and they all go back where they came from. There is nothing to get worn out or used up, so solar cells can last for decades.

In practice, we take a more effective way where the N layer is thinner and the P layer is thicker.

3.2.2 The advantages and disadvantages of photovoltaic solar energy

Photovoltaic solar energy has many advantages, for example, the free source of energy and the versatility. PV panels are also totally silent, producing no noise at all. And the most important advantage is that it provides us with green and clean energy.

Meanwhile, solar energy has intermittency issues. Consequently, intermittency and unpredictability of solar energy makes solar energy panels less reliable a solution.

3.2.3 Different types of PV cells

Monocrystalline silicon, polycrystalline silicon, and thin film are the three types of PV cell technology that now dominate the global market. Because of their high cost, higher efficiency PV technologies such as gallium arsenide and multi-junction cells are less prevalent, although they are excellent for concentrated solar systems and space applications. There is also an assortment of emerging PV cell technologies such as perovskite cells, organic solar cells, dye-sensitized solar cells and quantum dots.

3.2.3.1 Monocrystalline Silicon Cell

Monocrystalline silicon is a highly pure type of silicon, which was used to manufacture the first commercially viable solar cells. To produce these, a seed crystal is extracted from a molten mass of silicon, resulting in a cylindrical ingot with a single, continuous crystal lattice structure. They are highly efficient, but their production is sluggish and labor demanding, making them more costly than polycrystalline or thin film counterparts.

3.2.3.2 Polycrystalline Silicon Cell

A polycrystalline unit cell is made up of several tiny crystal grains rather than a single homogenous crystal structure. They are created by casting a cube-shaped ingot from molten silicon, sawing it, and packaging it as single crystal cells. Polycrystalline silicon photovoltaic cells dominated the global market as a less expensive but less efficient option, accounting for over 70% of global photovoltaic output in 2015.

3.2.3.3 Thin Film Cell

Despite the fact that crystalline PV cells dominate the market, thin-film PV cells are far more flexible and robust. Amorphous silicon (a-Si), which is made by depositing thin layers of silicon on a glass substrate, is one type of thin film PV cell. As a result, the cell is extremely thin and flexible, requiring less than 1% of the silicon required for a crystalline cell. Amorphous silicon cells are substantially less expensive to manufacture due to the lower cost of raw materials and a less energy-intensive production process. However, their efficiency is substantially lowered. These cells also have a 20% efficiency reduction in the first several months of operation before stabilizing, therefore they are sold with power ratings based on their reduced output.

3.3 Concentrating solar Power

3.3.1 The basic working principle of CSP

CSP systems use a mirror design that concentrates solar energy from the sun onto a receiver, which converts it to heat. The heat is subsequently turned to steam, which powers a turbine that generates electricity. CSP facilities can use thermal energy storage devices to store power until it is needed, such as during periods of low sunlight. Along with its capacity to store energy, CSP is a renewable energy source.

CSP systems can also be integrated with other forms of energy to form hybrid power plants. CSP, for instance, can be combined with thermal-fired power facilities that use fuels such as coal, natural gas, and biofuel.

3.3.2 The advantages and disadvantages of CSP

3.3.2.1 The advantages of concentrated solar power

Technically speaking, plants using fossil fuels can be used for CSP systems. The operating costs of CSP plants are relatively lower than those of hydrocarbon and nuclear plants due to the relatively simple operation and maintenance requirements. What's more, CSP can be used in combination with other energy sources to provide a more secure energy grid. When used in an energy mix, CSP can help meet future electricity demand. It can also help with oil recovery, as the steam it produces can be used to concentrate heavy oil, making it easier to pump. CSP also provides a relatively continuous source of electricity, especially when compared to solar photovoltaic (PV) and wind power, which provide intermittent supplies.It also has the potential to be used as a transportable form of energy.

3.3.2.2 The disadvantages of concentrated solar power

Concentrated solar power is largely dependent on location. A fundamental limitation or disadvantage of concentrated solar power is that it requires using extensive land area, which makes it uneconomical in populated areas. CSP plants can attract animals with its light, and the heat can be fatal for some species. They are also expensive to run. Thermal energy storage materials that can withstand high temperatures are costly and difficult to source.

3.3.3 The difference between solar photovoltaics (PV) and concentrated solar power (CSP)

Perhaps the biggest difference between solar PV and CSP is the way in which electric power is produced. CSP systems convert the sun's energy using various mirror configurations that drive a heat engine and produce electrical power.

Photovoltaic solar panels, on the other hand, use the sun's light, rather than its energy. Unlike CSP, PV converts light into electricity directly. The solar PV cells absorb light (rather than reflect heat), which stimulates electrons that create a current. The direct current (DC) is captured and converted into an alternating current (AC) using inverters so it can be distributed on the power network.

CSP systems store energy through Thermal Energy Storage technologies (TES), so power can be used when there isn't enough sunlight. PV systems, however, can't store thermal energy because they use direct sunlight, rather than heat. For this reason, CSP systems are better for energy storage and efficiency.

3.3.4 Different types of industrial thermal systems

3.3.4.1 Parabolic trough

Parabolic trough is a set of concave mirrors that concentrate solar rays on the receiver tube that is located in the focus. To maximize the efficiency, mirrors would trace sunlight, adjusting angles accordingly.

Synthetic oil or molten salt mixture, including 60% sodium nitrate and 40% potassium nitrate is usually used to circulate through the heat exchanger tubes and absorb heat concentrated by the mirrors. This fluid usually gets heated up to 400–600℃. These salts have a higher heat capacity than water, so some of that heat energy can be stored before using it to boil the water, which drives the turbines. These higher operating temperatures also allow for greater efficiency and mean that some power can be generated even on cloudy days.

3.3.4.2 Solar power tower

Solar power tower uses large flat mirrors to reflect sunlight onto a solar receiver at the top of a centrally located tower. It also uses heliostats which track the sun.

It has many interesting and useful designs. Firstly, some concentrating solar power towers are air-cooled instead of water-cooled, to avoid using limited desert water. Secondly, flat glass is used instead of the more expensive curved glass. Last but not least, although part of the light is used to generate the electricity directly, another part is stored in the molten salt tanks. Combined with some kind of energy-storage device, this means solar towers can produce reliable energy 24 hours a day.

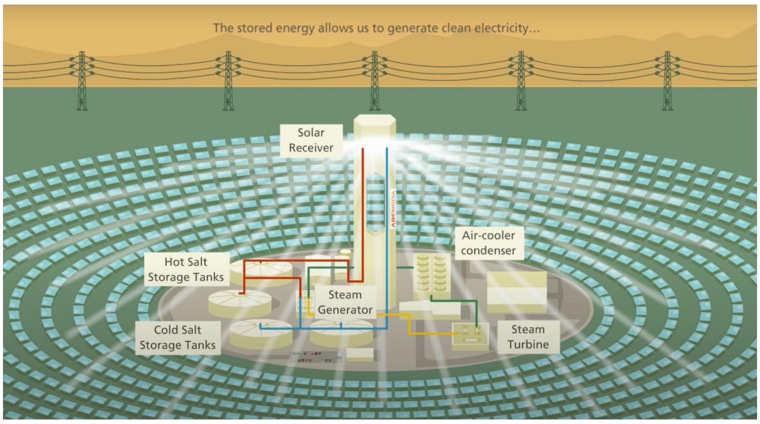


Figure 14 : The component of the solar power tower system [14]

3.3.4.3 Compact linear fresnel reflector

Compact linear fresnel reflector also uses flat mirrors. Its special layout of the mirrors has many advantages in the practice. It suffers low wind load and has slim foundations. Furthermore, this technology is much cheaper to install. Features that enhance the cost effectiveness of this system compared to that of the parabolic trough technology include minimized structural costs, minimized parasitic pumping losses, and low maintenance.

3.4. Solar energy in France

Due to lack of place, this whole section has been moved to the appendix [6.2].

3.5 Application to a specific house in Darnetal

We will now work on a specific house whose address is 26 rue de Lombardie, Darnétal. The house has a 96 m^2 area of living and there would be a family of 4 living in it.

To allow a family to live comfortably in this house using mainly solar energy we decided to provide the house with solar panels (for electricity) and a solar heating system. Regarding the solar heating system, we thought about two different possibilities: Trombe Walls or solar radiators. In order to check if one system could satisfy the consumption of energy of the whole house, we are proposing to calculate their costs separately.

However, we consider that this house has been built, which means it is not practical to install the Trombe walls. Therefore, we decide to define two situations. One is for a new house being built and another one is for a house built where we will use two systems : solar panels and solar radiators.

3.5.1 Case of the existing house

3.5.2.1 Solar panels

Firstly, we searched the annual consumption of a household with around 4 occupants. Our specific house is around 90 m^2 so we choose 14520 KWh as the yearly power consumption.

Energy Profile	Yearly power consumption	EDF Regulated tariffs for electricity	Online and Green offer	TotalEnergies Classic Electricity offer
30 m² apartment with collective heating and water heating, 2 occupants	1669 kWh	391 €	365 €	381 €
80 m² apartment with electric heating and water heating, 4 occupants	14 520 kWh	2519 €	2297 €	2429 €
180 m² house with electric heating and water heating, 5 occupants	26 746 kWh	4536 €	4954 €	4370 €

Figure 15 : Assessment of yearly power consumption and cost by three companies [15]

Then, in order to clarify the energy consumption for different uses, we devoted to searching those percentages respectively. According to the data collected and published by Eurostat, we could see that households use energy for various purposes: space and water heating, space cooling, cooking, lighting and electrical appliances and so on. In 2019, the main use of energy by households in the EU was for heating their homes (63.6% of final energy consumption in the residential sector). The details of the specific energy ratio are in the appendix [6.1.4].

Lastly, we aim to accumulate the energy needed for each season. It is a difficult part because in the beginning, we just took a rough calculation that divided the yearly consumption by 4. However, it is not rational that we consume the same energy in winter and in summer because we don't use the heating system in summer ! Typically, heating systems are used from October 15th to April 15th of the following year in France. Therefore, we set different numbers of months for each use and we obtain the final results represented in the following table.

Percentage of energy for different uses	Constant	Number of month	Winter	Autumn	Summer	Spring
Space heating	0,636	6	0,6	0,4	0	0
Water heating	0,148	12	0,25	0,25	0,25	0,25
Lighting and appliances	0,14	12	0,25	0,25	0,25	0,25
cooking	0,06	12	0,25	0,25	0,25	0,25
others	0,016	12	0,25	0,25	0,25	0,25
Total energy that we consume per year	14520	KWh				
The energy that we need for each season		14520	6862,152	5015,208	1321,32	1321,32

Figure 16 : The energy that we need for each season

After calculating the energy we need, we moved to the choice of solar panels. We select the second best solar panel from the top 10. The ranking is given by the site SolarEdition. Afterwards, we choose a product "JINKO 450Wp cadre noir IP68" from its official site. The parameters of this product are shown in the graphs below.

Mechanical Characteristics	
Cell Type	P type Mono-crystalline
No. of cells	120 (6×20)
Dimensions	1903×1134×30mm (74.92×44.65×1.18 inch)
Weight	24.2 kg (53.35 lbs)
Front Glass	3.2mm,Anti-Reflection Coating, High Transmission, Low Iron, Tempered Glass
Frame	Anodized Aluminium Alloy
Junction Box	IP68 Rated
Output Cables	TUV 1×4.0mm^2 (+): 400mm , (-): 200mm or Customized Length

Figure 17 : Mechanical characteristics of the product [17]

The most difficult part is to access the number needed for the solar panels. There are various factors to consider.

To begin with, the power of the solar panel is affected by temperature. Thus, it is necessary to calculate the operating power (Wp) according to the average sunshine hours (h) and average temperature for sunny days. By studying the brochure of the product, we notice that the maximum power in 20°C in NOCT (Nominal Operating Cell Temperature temperature) and coefficient of pmax is -0.35 %/°C.

SPECIFICATIONS

Module Type	JKM440M-60HL4 JKM440M-60HL4-V		JKM445M-60HL4 JKM445M-60HL4-V		JKM450M-60HL4 JKM450M-60HL4-V		JKM455M-60HL4 JKM455M-60HL4-V		JKM460M-60HL4 JKM460M-60HL4-V	
	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax)	440Wp	327Wp	445Wp	331Wp	450Wp	335Wp	455Wp	339Wp	460Wp	342Wp
Maximum Power Voltage (Vmp)	33.72V	31.39V	33.82V	31.56V	33.91V	31.73V	34.06V	31.91V	34.20V	32.07V
Maximum Power Current (Imp)	13.05A	10.43A	13.16A	10.49A	13.27A	10.55A	13.36A	10.61A	13.45A	10.67A
Open-circuit Voltage (Voc)	41.02V	38.72V	41.10V	38.79V	41.18V	38.87V	41.33V	39.01V	41.48V	39.15V
Short-circuit Current (Isc)	13.73A	11.09A	13.79A	11.14A	13.85A	11.19A	13.93A	11.25A	14.01A	11.32A
Module Efficiency STC (%)	20.39%		20.62%		20.85%		21.08%		21.32%	
Operating Temperature(°C)	-40°C~+85°C									
Maximum system voltage	1000/1500VDC (IEC)									
Maximum series fuse rating	25A									
Power tolerance	0~+3%									
Temperature coefficients of Pmax	-0.35%/°C									
Temperature coefficients of Voc	-0.28%/°C									
Temperature coefficients of Isc	0.048%/°C									
Nominal operating cell temperature (NOCT)	45±2°C									

*STC: Irradiance 1000W/m² Cell Temperature 25°C AM=1.5

NOCT: Irradiance 800W/m² Ambient Temperature 20°C AM=1.5 Wind Speed 1m/s

Figure 18 : Specifications of the mechanical characteristics of the product [18]

We have extracted the important characteristics and made a table as follows.

Temperature coefficients of Pmax	-0,0035	%/°C	Price of one product	300	€
In which temperature we have the 100% Pmax	20	°C			
Pmax in 20 °C	335	Wp			

Figure 19 : Summary of the important characteristics

Secondly, Darnétal is located in Normandy, a rainy region. We could suppose that the sunlight hours vary considerably from day to day within a season, even within a month. Consequently, we find the average sunshine hours and average temperature for sunny days from the site google. We also calculate other terms by the following formula :

- $Wp = Wp_{20°C} \times$ (Average temperature - 20) × (- 0.0035)
- Energy produced = Average sunshine hours × Operating power × Number of the days per month / 1000
- Nb of solar panels = Energy needed / Energy produced
- Cost = Nb of solar panels × The price of one product

Finally, all the results are shown as belows.

Month	Average sunshine hours (h)	Average temperature for sunny days	Operating power (Wp)	Energy (Kwh)		Total energy that we produce	Nb of solar panel that we need	Total cost (€)
January	3.7	6.0	351.415	40.307				
February	4.8	7.0	350.243	47.073				
March	5.6	10.0	346;725	60.191	spring	221,078	7	2100
April	7.6	14.0	342.035	77.984				
May	7.9	17.0	338.518	82.903				
June	9.3	20.0	335.000	93.465	summer	272,623	6	1800
July	9.2	22.0	332.655	91.813				
August	8.5	23.0	331.483	87.346				
September	7.3	18.0	337.345	73.879	autumn	175,716	30	9000
October	5.7	15.0	340.863	60.230				
November	4.0	10.0	346.725	41.607				
December	4.0	7.0	350.243	43.430	winter	130,810	53	15900
Total				80.023				

Figure 20: Final results of 100 % using solar panels

At the same time, for the case of operating power of solar panels between 9 and 36 kWp, the help for installation is 160 €/kWc. By multiplying the working hours and the average tariffs for a worker, we obtain roughly the installation cost. Finally, we could assess the total cost, which is 24109.20 €.

Working hours (h)	210
Average tariff for a worker (€/h)	55
Installation cost (€)	11550
Additional cost (€)	2000
Governmental installation help (€)	2 840,80
Governmental subsidy (€)	2500
Total cost of the solar panels part (€)	24 109,20

Figure 21 : Calculation of the total cost

3.5.2.2 Solar space and water heating

The problem of this part is easy to understand, but hard to implement. Basically, we want to know how many solar collectors we need to provide enough energy for space and water heating. We chose to use hot water for space heating since we will use solar collectors. We chose this system :

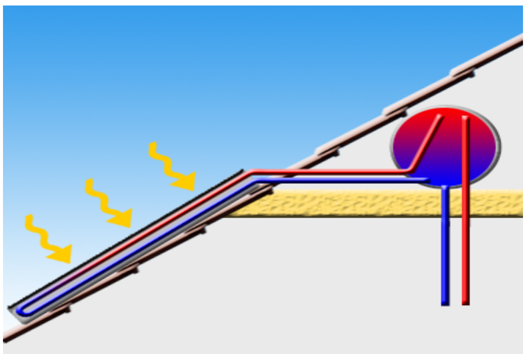


Figure 22 : Thermosiphon water heater [22]

We can get the number of collectors using these formulas :

- $Q_{solarIn}$ = SolarIntensity × Efficiency
- Q_{out} = Trise × Flow Rate × Specific Heat

Where $Q_{solarIn}$, Q_{out} and the SolarIntensity are in kWh, Efficiency being the efficiency of the collector, Trise the difference of temperature of water at the outlet and the inlet of the collector, FlowRate the flow rate of water in the collector in kg/m3 and SpecificHeat the specific heat of the liquid (here water, which is : 4184 J/K/kg).

If we consider that the flow is permanent and that the pipes and the pump do not add some heat loss we can say a few things :

$Q_{solarIn} = Q_{out}$

FlowRate in collector = FlowRate in radiators

Trise = deltaT which is the difference of temperature at the outlet and the inlet of the radiators

Depending on the power needed to heat the house, we will be able to determine the flow rate of the water at a certain temperature needed to heat the house. We will then choose the solar collector in consequence.

1. Irradiance and temperature in Darnétal

This part has been hard to understand. First, there's a difference between "irradiance" and "irradiation". Irradiance is a measure of solar power whereas insolation (or irradiation) is a measure of solar energy. In fact, what we want is the irradiance since we don't want to know how much energy will be produced if not just the power of the sun in Darnétal.

We searched for the irradiance of the sun (W/m^2) and the exterior temperature in Darnétal. We took this data from a software named PVGIS, which is official data of the European Union, and especially the PVGIS-SARAH2 database. In the section "AVERAGE DAILY IRRADIANCE DATA" of PVGIS we got the average solar irradiation for each hour during the day for a chosen month, with the average taken over all days in that month during the multi-year time period for which the database have data. We would like to specify that this irradiance is calculated at the optimum slope and azimuth which corresponds to 37° and 2°. The solar collectors will then need to be facing corresponding to these angles.

Of course you don't heat your house in summer. In fact, the heating period is usually from october 15th to april 15th of the next year in France. By looking at the lowest average monthly temperatures in Darnétal, we note that the worst month is January with a temperature of 4,61875 °C. The average irradiance for one day in January is 62.60333333 W/m^2. We did the next calculations with this worst case to be sure that we will be able to heat the house over the whole year.

2. Power needed for the radiators

Now, the question is how much power is needed to heat the house by the radiators. The power depends on the volume of the rooms that we want to heat, on which room the radiator is placed, on the insulation of the house, on the localisation of the house and on our subjective preferences of heating.

We couldn't visit the house, but we were able to manually calculate the heating power needed using this formula :

- Heating power of a radiator = heat loss coefficient × volume of the room in m3 × (desired indoor temperature – outdoor temperature) ⇔ P = D×V×(tint-text)

If we consider a living area of 96 m² (calculated approximately with google maps), one kitchen, two bathrooms/toilets, three bedrooms and one lounge/dining room where this last is twice as big as the others, we end up with a volume of 60 m3 for the lounge and 30m3 for the others.

The ideal temperatures vary between 18°C and 24°C (for example, 24°C for a bathroom and 18°C for a bedroom), the full calculation sheet is in the annexes.

The calculation of the Heat loss coefficient is quite complex to calculate since it varies on each house. This work can be done well by a thermal engineer if we have access to the house. But since we can't, let's suppose that the insulation is "normal", then the deperdition coefficient is 1,6.

Since the coldest month of the year seems to be January (with an average temperature of 4,61875°C from 2005 to 2020), we can calculate the total maximum power of all the radiators needed. Thus, the result is 6194,4 W to provide in January.

Here are some radiators we can use for this house:

(ref 82060566) by Leroy Merlin costs 116 € and can provide 1683 W of heating power.

(ref 66271870) also by Leroy Merlin costs 83,90 € and can provide 662W of heating power.

(ref 66272031) still by Leroy Merlin, costs 95,90€ and can provide 750W of heating power.

3. The flow rate needed

Now concerning the flow rate. To determine the flowrate of water that we need to have to supply these radiators, we use this formula :

- D = P / (Delta T × Ce × p × 10^(-3)) × 1,20

DeltaT = 15, Ce = 1,1628 specific heat of water, p = volumic mass of water (depends on the temperature of the water) and D is in kg/h but can be approximated in L/h without a lot of errors. For the temperature of water, let's take 55°C. Then, p = 985,7 kg/m^3. In the calculation sheet, we made a 3rd degree polynomial interpolation of this volumic mass with the temperature to make it easier to read.

Then, D = 6194,4/(15 × 1,1628 × 985,7 × 10^{-3}) × 1,20 = 432,3539724 L/h = 7,205899541 L/min. When we add other hot water consumption (for cooking and showers for example) we then get 7,34L/min. Our solar collector must supply water at least at the temperature of 55°C and at a rate of 7,34L/min.

4. Number of collectors determination

By resolving :

$Q_{solarIn} = Q_{out}$

⇔ SolarIntensity × Efficiency = Trise × FlowRate × SpecificHeat

⇔ Irradiance × Surface × Efficiency = DeltaT × Flow Rate × Specific Heat

⇔ Surface = (Delta T × Flow Rate × Specific Heat) / (Irradiance × Efficiency)

We can eventually get the surface needed to heat the house. By comparing the different collectors available on the market, we think that the best one is the Linuo Paradigma / FP2000 since it is the least expensive. The number of collectors needed would be 88 for a surface of more than 170 m^2, which is a lot. In fact, this is too much. We only have 100 m^2 of roofs on our field, and it should be shared with the solar panels ! Even if the collectors had a 100% efficiency it would require around 123 m^2 of surface. We could put the collectors on the ground or on a structure above the ground (to keep the space of the field) if we really wanted to make it 100% solar. This is actually possible since the total surface of the house field is 660 m^2.

If we consider that we use the collectors for only water heating, the numbers become much more realistic and the best model becomes the Vaillant / VFK 135/3 VD (Dutch quality!) that would take 4.5 m^2 of surface only for a number of 2 collectors.

5. Price of the collectors system

As we saw in the previous part, we would need 88 collectors to provide enough heating in January. The price for these collectors would be 6,156.48 € not including the tank, the pipes, the control panel and the pump(s). The price of the latter is hard to predict but by comparing different prices on the net and making it the most realistic possible, we chose 3,000.00 €. The total would then be around 9,156.48 €.

If we choose to use a 50/50 solar heating, i.e. using both a gas boiler and solar collectors, the price of the collectors would then be cut in half, amounting the total to 6,078.24 €.

However, the France estate offers bonuses for people who install these systems, and for the heating the help can reach 4 000 € for the most modest and 2 500 € for superior earnings. The final price of the collectors system would then amount to 6,656.48 € for 100% solar and 3,578.24 € for 50% solar.

As for the water only part, the total cost would be 1,268.30 € including the government help.

3.5.2.3 Combination of solar panels and collectors

In this part, we will combine two systems: solar panels and solar radiators (100% solar).

To achieve it, we change the coefficients for the use of space heating for the solar panels to 0. And we get the final number of solar panels needed, which is 7 in the worst situation. We also need 88 collectors at the same time which cost around 6,656.48 €.

Percentage of energy for different uses	Constant	Number of month	Winter	Autumn	Summer	Spring
Space heating	0,636	6	0	0	0	0
Water heating	0,148	12	0	0	0	0
Lighting and appliances	0,14	12	0,25	0,25	0,25	0,25
cooking	0,06	12	0,25	0,25	0,25	0,25
others	0,016	12	0,25	0,25	0,25	0,25
Total energy that we consume per year	14520	KWh				
The energy that we need for each season			784,08	784,08	784,08	784,08

	Total energy that we produce	Nb of solar panel that we need	Total cost (€)
spring	221,078	5	1500
summer	272,623	4	1200
autumn	175,716	5	1500
winter	130,810	7	2100

Figure 23 : Calculation of total cost in the case of combination

As was shown in the previous parts before, the yearly regulated tariffs for a 80 m^2 apartment with 4 occupants is around 2519 € assessed by the company EDF. Additionally, we could sell the surplus electricity after self-consumption at the price of 0.1 €/KWh. Thus, after considering all the possible factors, we could get the payback after 4 years.

Working hours (h)	30
Average tariff for a worker (€/h)	55
Installation cost (€)	1650
Additional cost (€)	2000
Governmental installation help (€)	891.10
Governmental subsidy (€)	0
Total cost of the solar panels part (€)	2,858.90
Total cost of the solar collector part (€)	6,656.48 €
Total cost (€)	9,515.38

	The energy that we can sell (KWh)	Revenue (€)
Spring	763.469	76.347
Summer	1124.284	112.428
Autumn	445.932	44.593
Winter	131.590	13.159
Feed-in tariff for the surplus electricity (€/kWp)	0.1	
The help for installation between 0 and 3 (€/KWp)	380	
Total revenue (€)		246.527
Yearly regulated bill(€)		2519
Payback in a few years		4

Figure 24 : Calculation of possible revenue and payback years

3.5.2 Case of a new house

Here, we are considering building a house following the same plan as the one that already exists but instead the two main walls of the house would be Trombe Walls instead of regular ones.The walls of such a two-story house have a height between 4.4 m and 5.8 m. The length of the house being approximately 10.69 m, the two principal walls have thus a surface comprising between 47.04 m² and 62.002 m². To equip these two walls with a Trombe wall would thus cost between 4469 € and 5890 € at a rate of 95 €/m².

These Trombe Walls are able to warm up or cool down the interior space between 6 and 10 degrees Celsius.

We would also use the solar panels mentioned above for the electricity heating when necessary as well as the heating system but only for water.

The total maximum price would then be 5890 (Trombe wall) + 2858.90 (solar panels without space heating) + 1268.30 (water only heating) = 8750.17 € considering that the Trombe walls are sufficient to heat the house entirely.

4. Conclusions and perspectives

First of all, we studied various applications of solar energy in life. We mainly divided the applications into two parts: the application of solar energy in electricity and the application of non-electricity. In the application of non-electricity, our research includes the working principle of solar oven, solar water purification system, solar dryer and Trombe wall. In addition, we mainly divide the application of solar energy for electricity into photovoltaic power generation and concentrating solar power generation. We have studied their types and working principles and the advantages and disadvantages and differences. At the end of the first part we listed the typical application cases in France as above.

After that, we used the real house with the address of 26 rue de Lombardie, in Darnétal to build a model. Firstly, we set up a general model for a family of four, and got the total electricity consumption. With reference to local weather, sun exposure, average temperature and other factors, and combined with the actual area of the roof of the house, we obtained the number of photovoltaic solar panels required in the worst case, that is in winter, and then we considered that Photovoltaic solar panels and solar water heating systems are combined, so that the hot water and heating parts are borne by the solar water heating system, and finally combined with government subsidies, installation and maintenance fees, we calculate the total cost, and then we take into account the income from the extra energy what can be sold plus the savings from not using conventional power will finally yield a payback in 4 years. That is to say, after 4 years, electricity and heating for this house are free, and we can even earn income from selling excess solar energy.

To conclude, it can be seen that from the most basic economic point of view, the application of solar energy systems in the home is very worthwhile. In addition, from the perspective of environmental protection, solar energy as a renewable energy source is more environmentally friendly than traditional electricity. The current situation of shortage, perhaps in the future, the application of solar energy systems in households will bring great help to solve the energy crisis.

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6. Annexes

6.1 Technical documentation

6.1.1 Space and water heating calculation sheet

room	T_room_wanted (°C)	Surface Area (m2)	Height (m)	Volume_room (m3)	Power_max_needed (W)	Number_of_rooms	T_ext_jan (°C)	D_coef	
bathroom	24	12	2.5	30	930.3	2	4.61875	1.6	
kitchen	20	12	2.5	30	738.3	1			
lounge	22	24	2.5	60	1668.6	1			
bedroom	18	12	2.5	30	642.3	3			
input				Total	6194.4				
output									
constants									
Hot water needed other than space heating (L/4pers/day)	T of water (°C)	volumic mass of water (kg/m3)	Flowrate needed for Space Heating (L/h)	Flowrate needed for Water heating (L/h)	Flowrate needed for General heating (L/h)	DeltaT (°C)	Ce		
200	55	985.7477692	432.3330206	8.333333333	440.666354	15	1.1628		
G(i)_jan (W/m2)	Specific Heat of Water (	Brand / Model	Solar collector efficiency	Surface of collector needed (general heating) (m2)	Surface of one collector (m2)	Number of collectors	Price per collector (euro)	Total price (euro)	Comments
62.60333333	4184	SUNRAIN / FPC1500C	0.70	175.3052121	15	12	1,000.00 €	12,000.00 €	
		GREENoneTEC / SUNPAD	0.91	134.8501631	1.68	81	2,499.00 €	202,419.00 €	
		Linuo Paradigma / FP2000	0.72	170.4356228	1.95	88	69.96 €	6,156.48 €	min 15 collectors on purchase
		Vaillant / VFK 135/3 VD	0.79	156.323119	2.35	67	634.15 €	42,488.05 €	
		Viessmann / Vitosol 200-FM x1	0.82	149.6507908	2.33	65	3,712.00 €	241,280.00 €	
		Viessmann / Vitosol 200-FM x2	0.82	149.6507908	4.66	33	4,475.00 €	147,675.00 €	
		Viessmann / Vitosol 200-FM x3	0.82	149.6507908	6.99	22	6,731.00 €	148,082.00 €	
		Wolf / TopSon F3-1	0.70	174.3091597	2.3	76	782.55 €	59,473.80 €	
		Ideal model	1.00	122.7136484					
				Surface of collector needed (water heating) (m2)					
		Vaillant / VFK 135/3 VD	0.79	2.956188161	2.35	2	634.15 €	1,268.30 €	NO SPACE HEATING
		Viessmann / Vitosol 200-FM x2	0.82	2.830009398	4.66	1	4,475.00 €	4,475.00 €	NO SPACE HEATING
		Wolf / TopSon F3-1	0.70	3.296317765	2.3	2	782.55 €	1,565.10 €	NO SPACE HEATING
Price of the collectors (general heating)	Other costs	France estate help	Total cost (100% solar)	Total cost (50% solar)	Price of collectors (only water heating)	Total cost (100% solar)			
6,156.48 €	3,000.00 €	2,500.00 €	9,156.48 €	6,078.24 €	1,268.30 €	3,768.30 €			
		With help	6,656.48 €	3,578.24 €	With help	1,268.30 €			

6.1.2 Daily Irradiance in Darnétal

Latitude (decimal degrees):	49.445		G(i)_mean						
Longitude (decimal degrees):	1.152		62.60333333						
Radiation database:	PVGIS-SARAH2								
Results for:	January								
Slope of plane (deg.):	37								
Azimuth (orientation) of plane (deg.):	2								
time(UTC)		G(i)		Gb(i)		Gd(i)		T2m	
0:00			0		0		0		3.91
1:00			0		0		0		3.81
2:00			0		0		0		3.72
3:00			0		0		0		3.63
4:00			0		0		0		3.56
5:00			0		0		0		3.5
6:00			0		0		0		3.45
7:00			0		0		0		3.51
8:00			7.74		0		7.56		3.51
9:00			115.94		54.9		59.57		3.95
10:00			205.88		107.29		96.04		4.71
11:00			254.76		139.15		112.43		5.48
12:00			278.39		155.75		119.21		6.09
13:00			253.26		140.39		109.8		6.49
14:00			226.72		130.98		93.21		6.66
15:00			145.37		85.57		58.38		6.52
16:00			14.42		9.17		5.13		6.03
17:00			0		0		0		5.4
18:00			0		0		0		4.98
19:00			0		0		0		4.73
20:00			0		0		0		4.51
21:00			0		0		0		4.32
22:00			0		0		0		4.17
23:00			0		0		0		4.04
G(i): Global irradiance on a fixed plane (W/m2)									
Gb(i): Direct irradiance on a fixed plane (W/m2)									
Gd(i): Diffuse irradiance on a fixed plane (W/m2)									
T2m: 2-m air temperature (degree Celsius)									
PVGIS (c) European Union, 2001-2022									

6.1.3 Monthly Temperature in Darnétal

Latitude (decimal degrees):	49.445				
Longitude (decimal degrees):	1.152				
Radiation database:	PVGIS-SARAH2				
year	month	H(i)_m	T2m	T2m_mean_year	H(i)_mean_year
2005	Jan	59.94	5.80	4.61875	48.9125
2005	Feb	63.19	2.80	4.7375	70.570625
2005	Mar	90.26	7.10	7.04375	112.01375
2005	Apr	130.8	10.40	10.4125	152.19875
2005	May	151.14	12.70	13.41875	150.529375
2005	Jun	171.22	17.50	16.7125	154.860625
2005	Jul	138.59	18.00	18.63125	161.381875
2005	Aug	173.24	17.10	17.93125	148.8525
2005	Sep	129.42	16.40	15.65	134.34875
2005	Oct	102.79	14.90	12.3375	93.78125
2005	Nov	76.54	6.40	7.96875	60.2375
2005	Dec	45.31	3.70	5.16875	48.92625
2006	Jan	57.68	2.70		
2006	Feb	51.29	3.20		
2006	Mar	104.43	5.50		
2006	Apr	126.75	9.10		
2006	May	127.55	13.40		
2006	Jun	176.63	17.50		
2006	Jul	189.29	21.20		

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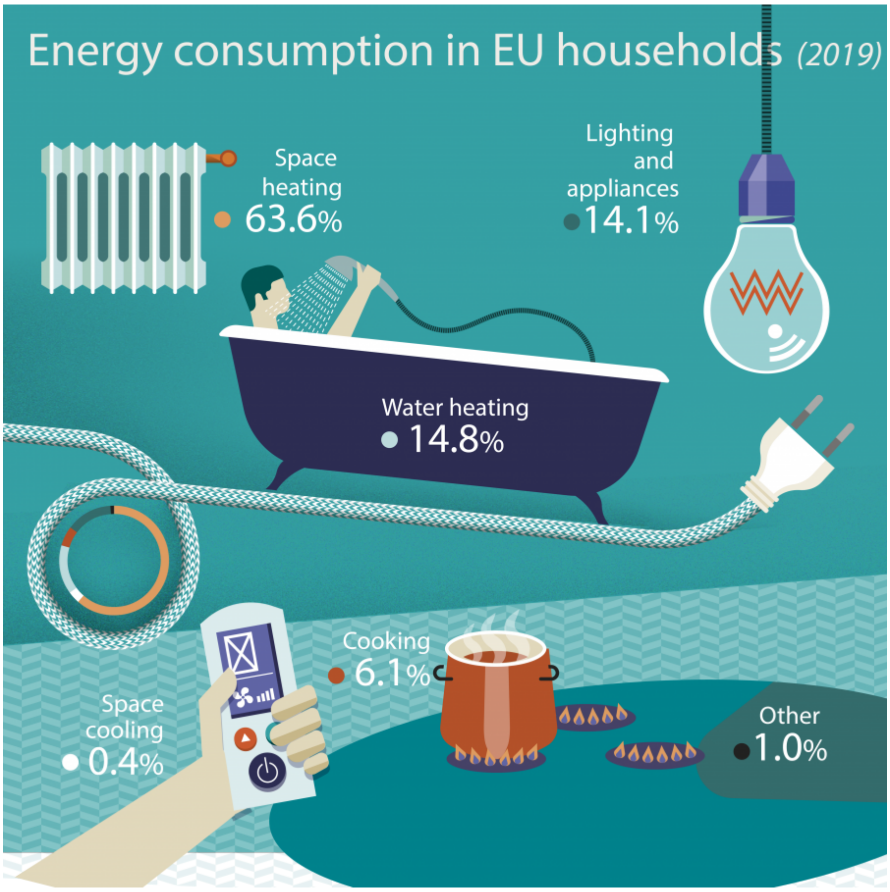
2019	Apr	160.38	10.30
2019	May	146.55	12.60
2019	Jun	162.67	17.40
2019	Jul	192.69	20.00
2019	Aug	162.46	18.90
2019	Sep	124.24	16.00
2019	Oct	75.06	12.70
2019	Nov	57.23	7.20
2019	Dec	49.15	6.50
2020	Jan	48.18	6.50
2020	Feb	61.17	7.70
2020	Mar	130.37	7.30
2020	Apr	185.17	13.20
2020	May	196.32	14.70
2020	Jun	150.66	17.00
2020	Jul	168.07	18.50
2020	Aug	145.7	20.50
2020	Sep	139.12	16.90
2020	Oct	76.55	11.90
2020	Nov	64.24	9.10
2020	Dec	42.74	6.10
H(i)_m: Irradiation on plane at angle (kWh/m2/mo)			
T2m: 24 hour average of temperature (degree Celsius)			
T2m_mean_year: average of T2m over the years			
H(i)_m_mean_year: average of H(i)_m over the years			

6.1.4 Energy consumption in europeens households of year 2019



6.2 Solar energy in France

6.2.1 Non-electric use of solar energy in France

6.2.1.1 Solar ovens

This part consists of a list of different solar ovens that are/have been used in France.

The first oven that we want to present which is the most important in France is the Odeillo solar oven. It is located in Font-Romeu-Odeillo-Via in the department of Pyrénées-Orientales at an altitude of 1 535 meters. It is one of the two biggest solar ovens in the world with a thermal power of one megawatt concentrating around 10000 times the power of the sun onto one point (this point can reach 3300°C).

Figure : Odeillo solar oven

The basis of working of this system is that it uses both plan mirrors and a parabolic one. The plan mirrors “collect” the sun beams and the parabolic one concentrates these beams onto one point.

The use of this solar oven is for a scientific purpose. Indeed, thermal shocks experiments are done since the temperature rises very quickly. On top of that, experiments about water cracking, energy conversion can be done as well as research on aerodynamics or spatial. It should be mentioned that the heating can be carried out in a controlled atmosphere allowing to reproduce spatial vacuum for example.

The second oven that we want to present is the Mont Louis solar oven which is the first one created in the world. Yes, solar ovens are a french innovation. This one is located in the town of Saint Louis just a few kilometers next to the Odeillo solar oven. You will be surprised to hear that the Mont Louis solar oven is the precursor of the Odeillo’s. It can supply a power of 50 kW.

The main use of this solar oven is for education, offering visits to everyone frequently. The guides tell the visitors the principle of working of a solar oven and show utilisations of the oven such as the burning of wood, melting of metal or ceramic cooking. They also teach the visitors how to build their own solar cooker and show them the cooking itself.

The last solar oven to present is a commercial one which can be bought on the site of the constructor (Solar Fire Ltd). Its name is the Lytefire 5 using the Fresnel mirror solar concentrator system. It is designed for cooking (bakery or roasting or both). The fact that you can choose every feature of it on the site makes it very modular. Indeed, it can be static or movable and you can choose the dimensions between 5 m² and 11 m².

Figure : Lytefire 5 solar oven

This model uses 3,5 kW of the sun's energy and can reach 300°C. Therefore, in Normandy, it can cook 5 to 8 batches of bread per day, each batch containing 24 kg of bread.

I would like to add that this model is used in a bakery in Normandy named neoloco in Montville at the north of Rouen.

6.2.1.2 Solar water purification systems

Now, concerning the water purification systems, they are very rare in France since they are not very useful in our country because water is in majority easily obtainable. However, we found a unique company who created a water distillation system in France named Marine Tech with its device named Hélios. The distillation process works the same as the others already covered out in the introduction using salty water.

Figure : Helios picture & working principle

One bubble can produce 10 liters of water during 8 hours with a solar radiation of 8 kWh/m²/day. The advantages are that one pump can run simultaneously 5 bubbles and that it produces enough water for a family but the drawbacks are that it uses electricity (solar panel) and that it takes a lot of space.

6.2.1.3 Solar dryer

In France, solar dryers are mostly used by farmers for organic farming, for vegetable processing or more generally in the food industry. Mostly, French people use the indirect type of solar dryers because it’s safer for the food.

Even though they can be built, many French farmers buy prefabricated solar dryers. Here’s an example of a type of solar dryer that is used in France.

Figure : KSS Standard

The KSS Standard. It dries up to 3kg of fresh fruits from 6 AM to 6 PM depending on the sunshine.The Dimensions are 27 x 27 x 120 cm and it costs 175 €.

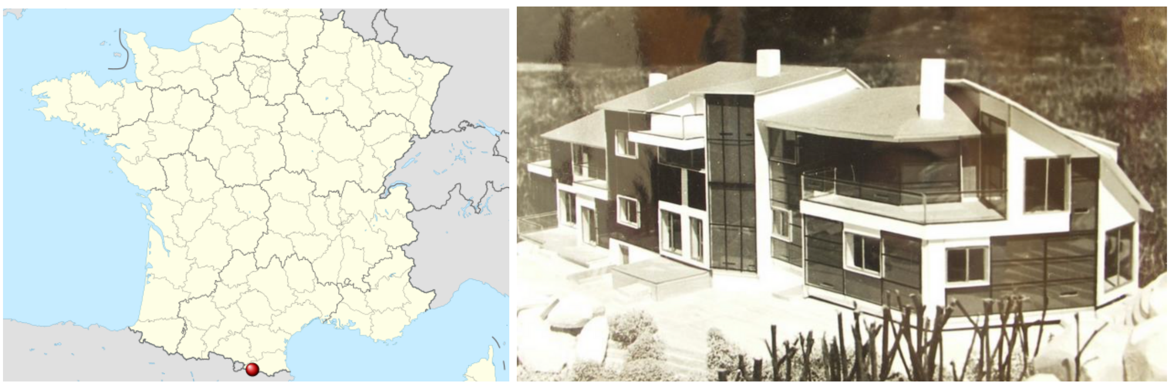
But generally, depending on the dimensions, the prices of solar dryers are between 150 € and 900 €.

6.2.1.4 Trombe Wall

Unfortunately, Trombe walls are not really popular in France. But we can still name some infrastructures where it is used: A solar wall has been used in the Lagorsse gymnasium (Ile-de-France) since 2010 and another one was adopted on a Toyota site in Onnaing (North) in 2011.

A Trombe wall costs around $100/m^2 (according to Solar Energy Technology Handbook by E. W. Dickinson) i.e. about 95 € in 2017.

Despite the fact that Trombe Walls are not really used, the Solar House building Trombe Michel commemorates this process. Indeed, built in 1974 in Font-Romeu-Odeillo-Via in the Western Pyrenees (South of France) , this building is entirely heated by the Tromb-Michel's process and is now considered a historical monument. Its construction has cost approximately 490600 francs i.e. 74792 €.



Figures : The solar house building Trombe-Michel and its location

6.2.2 Photovoltaic solar energy

6.2.2.1 Cestas Solar Park

The Cestas Solar Park is a 300 megawatt (MW) photovoltaic power station in Cestas, France. It opened in 2015.

Figure : Cestas Solar Park

It is one of the largest photovoltaic building sites in the world. This modern high-tech solar park extends over an area of 2.6 million m^2 the equivalent of 363 football pitches. The maximum output is about 300 MWp. 111000 households can be effortlessly supplied with electricity. This project can supply 111000 households. Around 230000 tonnes of CO2 are saved each year in comparison with a coal fired power station.

Photovoltaic project specifications for Cestas Solar Park, it was decided to choose fixed panels, sloping slightly from east to west which is the best solution for increasing the area and preventing shading.

Another feature of the project was the absence of concrete foundations. Instead, the frames for the PV panels were screwed directly into the ground. This solution makes sense from an environmental and economic point of view, making construction cheaper and faster.

Despite the simplicity and low cost of technology, Cestas demonstrates the highest level of technical reliability. Over the five years of operation, breakdowns have occurred extremely rarely. The average annual availability of equipment is 99%. When a single photocell fails, the panel changes quickly.

6.2.2.2 Deauville-Normandie Airport Solar PV Park

Project Type	Total Capacity (MW)	Active Capacity (MW)	Pipeline Capacity (MW)	Project Status	Project Location	Project Developer
Solar PV	60	–	60	Permitting	Normandy, France	EDF Renewables

Figure : Project description

Deauville-Normandie Airport Solar PV Park is a 60MW solar PV power project which is planned over 45 hectares.

The project is expected to supply enough clean energy to power 21,000 households, to offset 700,000t of carbon dioxide emissions (CO2) a year.

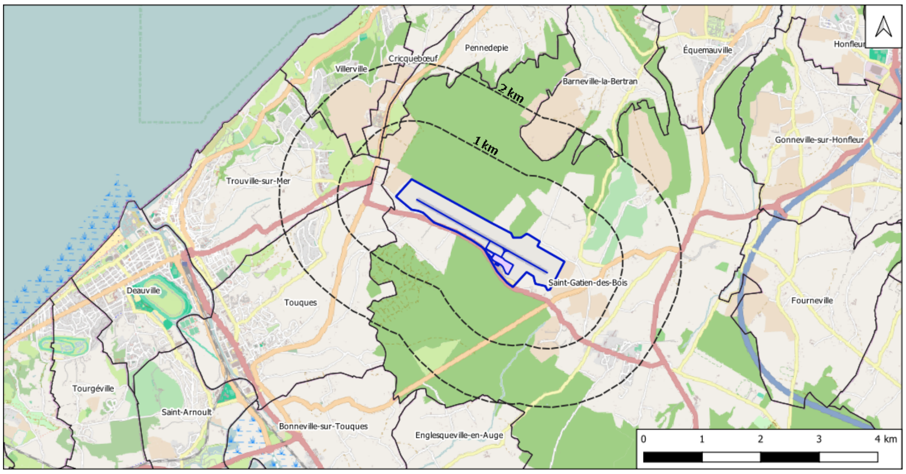


Figure : Geographical location

6.2.3 Concentrating solar power

Generally, concentrated solar thermal has only a marginal contribution in France. Many companies in the sector went into liquidation. There are two important existing examples.

6.2.3.1 Themis Solar Power Plant

The installation is composed of 201 heliostats. The tower is now used to develop new processes for the recovery of concentrated solar energy thanks to 2 experimental areas : One at the historic foyer where 4 MWth of energy is available thanks to 117 renovated heliostats, and a new one on a smaller scale of 150 kWth. The focus is on processes at higher temperatures than the original system to achieve better thermodynamic conversion efficiency: 700 or even 1,000 °C rather than 350 °C.

Figure : The heliostats of the Themis solar power plant

6.2.3.2 ello

Near the port of Llo (1579 m), the solar power plant ello is located in Cerdanya, one of the sunniest places in the metropolitan territory thanks to special weather conditions: dry climate, fairly high altitude and distance from urban centers guarantee a particularly clear atmosphere for a large part of the year.

ELLO is a thermodynamic solar power plant of 9 MW electric type Fresnel linear type equipped with 95,200 mirrors, following the course of the sun to heat long fixed tubes and produce water vapor. This steam can be stored in 9 balloons corresponding to 4 hours of production, or directly used to generate electricity. Thanks to the thermal storage system, electricity production can be carried out at the request of the grid operator, including at night, and not only when the weather permits.

6.3 Assembly diagrams, design plans…

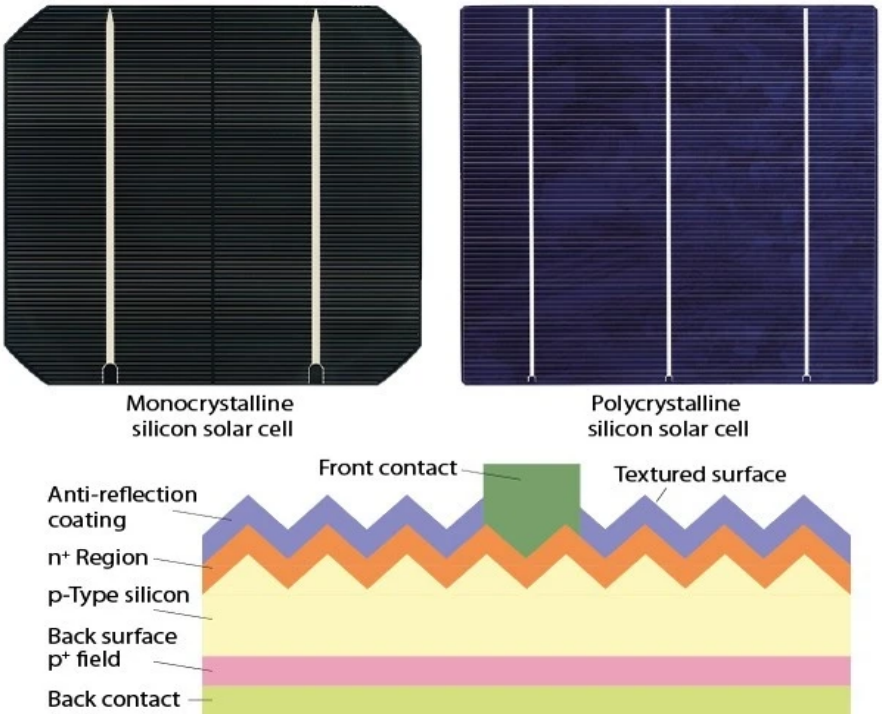


Figure : Monocrystalline and polycrystalline Silicon Cell

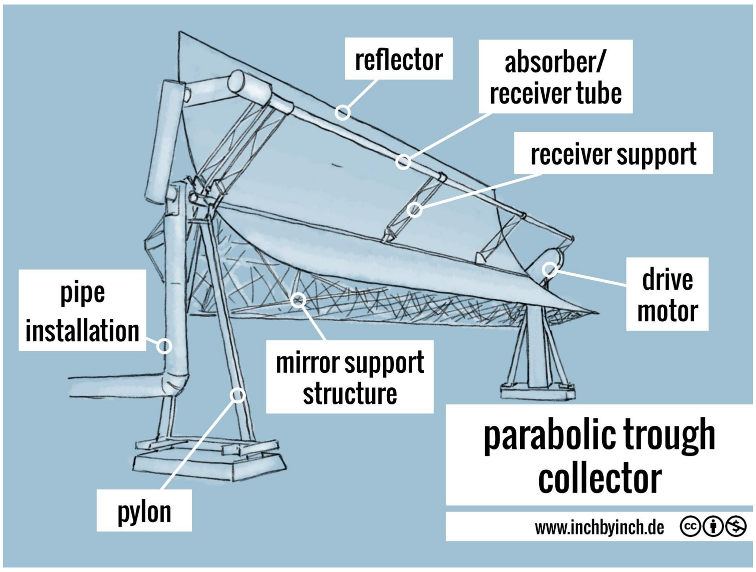


Figure : The components of the parabolic trough

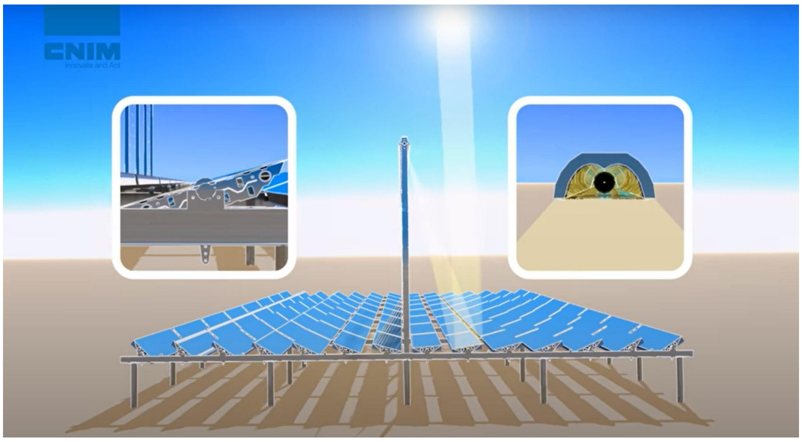


Figure : The special layout of the mirrors

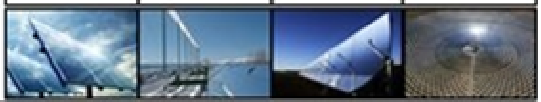
	PV	Fresnel	Parabolic Trough	Tower
				
Production of thermal energy		☑	☑	☑
Cost Investment	☑	☑		
Maintenance Cost	☑	☑		
Production Flexibility		☑		☑
Local Content		☑	☑	☑
Thermal Storage		☑	☑	☑
Land Easement	☑	☑		

Figure : Comparison between different systems

6.4 Proposals for project topics

6.4.1 Some Trombe walls around the world

Figure : A building using Trombe wall as a passive solar strategy in Hopfgarten, Austria

Figure : A school with a Trombe wall in Salta, Argentina

6.4.2 Other applications of solar energy to the house in Darnetal

We could also add a KSS Standard that would give to the family a new way to store food.