ETUDE ET CONSTRUCTION D'UN CHAUFFAGE SOLAIRE AEROTHERMIQUE POUR L'HABITAT

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STUDY AND CONSTRUCTION OF A AEROTHERMAL SOLAR PANEL FOR HOUSING

Lycée Comte de Foix

CLASSE de 1ère SECTION EUROPÉENNE - PHYSIQUE CHIMIE

Entreprise formatrice partenaire ENERLOG : https://www.enerlog.fr/

Partenaires du projet :

FEDA https://www.feda.ad/

HERACLES https://www.grupheracles.com/es/Inicio

SUMMARY:

In a context of energy saving and increased need for sustainable and renewable energy, we proposed, with the technical support of a partner company ENERLOG, an aerothermal solar panel to heat the habitat from solar radiation.

This low-tech project, still little known to the general public, construction and energy distribution companies, uses locally available and sustainable materials such as slate and wood.

Andorra being a country with a high rate of annual sunshine with a mountain climate and booming real estate construction, this low-tech accessible to all could make it possible to offer interesting energy saving prospects to the scale of a house.

VIDEO LINK YOUTUBE OF OUR PROJECT:

https://youtu.be/i_f5asHIzWY

TEAM PRESENTATION:

We are a class of 14 students from 1ère Section Européenne in Physics and Chemistry from the Lycée Français Comte de Foix located in Andorra.

Each week we follow 1 hour of additional physics and chemistry class in English.
We have worked since the beginning of the year on the theme of energy and in particular studied its sources, its forms and the various means of production and conversion such as power stations, wind turbines, solar panels, batteries and the systems used by man to sustain and distribute energy.

Fig 1: Students during the construction of the aerothermal solar panel

STUDENTS:

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INTRODUCTION:

We started from the problem **"How to achieve energy savings in Andorra, using renewable and sustainable energy sources?"**

In Andorra, solar energy is one of the most accessible and economical sources. In order to use this source of energy, we looked for an innovative technology that could make it possible to exploit it.

The aerothermal solar panel met this need perfectly because it uses sustainable and local materials such as slate and wood. It also makes it possible to achieve significant energy savings in a home.

We thus came into contact with the company ENERLOG based in Nantes and asked them to help us in this process to build with their guidance an aerothermal solar panel.

In order to achieve this project, we searched for sponsors who could help us financially. We created a document to present our goals and made oral presentations of our project to different persons many times.

Several companies in the real estate or energy sector have shown themselves concerned: FEDA (electrical forces of Andorra), HERACLES (construction), El Pastador (local company), as well as organizations wishing to support our approach: the Arts et Métiers Foundation and the Rotary Club of Andorra.

Our project was able to come into existence in March. We went to the city of Nantes during one week to make the aerothermal solar panel with the team of our partner company ENERLOG composed of a thermal engineer, two engineering students and a carpenter. It was a collaborative and team work, divided into three groups, each group making a panel.

We also received theoretical training on the operating principle of the panel and on the use of an Arduino microcontroller to record data (temperature, humidity) and activate the panel fan.

Several performance and thermal efficiency calculations were carried out with the help of the ENERLOG engineering team to find out if our panel would be suitable for the Andorran environment.

The documentation and information freely available on the Wiki of the Enerlog site allowed us to learn more about the operation of the panel.

Fig 2: Students presenting in Catalan the project to the FEDA company leaders

PROBLEM:

"How to achieve energy savings in Andorra, using renewable and sustainable energy sources?"

PRESENTATION OF THE AEROTHERMAL SOLAR PANEL

PRINCIPLE OF OPERATION:

The sun is a major natural source of energy. Its radiation allows it to heat a house thanks to a simple system called aerothermal solar heating.

The aerothermal solar panel stores solar energy and restores it to the home autonomously. A circuit allows air to be pulsed in the habitat up to 70°C. This ecological solution makes it possible to reduce the share of energy used for heating the home and to expel humidity.

For a better understanding of its performance, here is a cross-section of the panel.

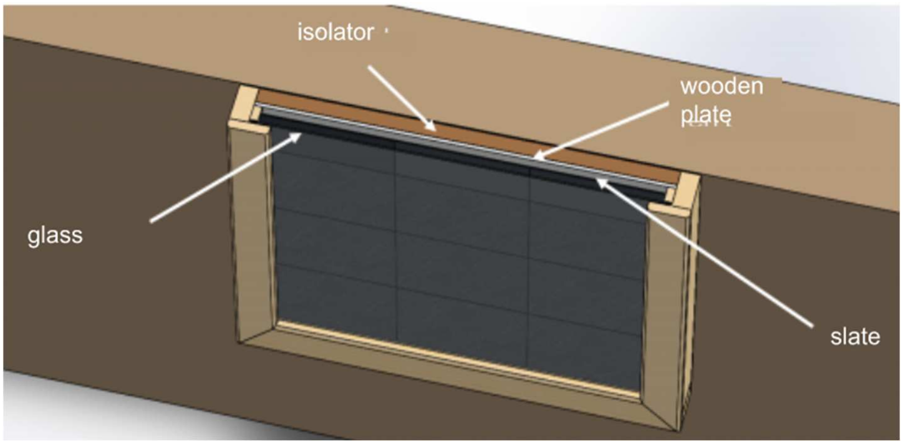


Fig 3: cross section of the panel - Image from the Wiki Enerlog

First, we can see that between the slates and the glass at the front of the panel there is a first space filled with static air.

A second space between the slates and a wooden plate behind contains air in motion.

Then, finally, an isolator, located behind the wooden plate, helps to limit the possible heat losses.

We can summarize the process in four steps:

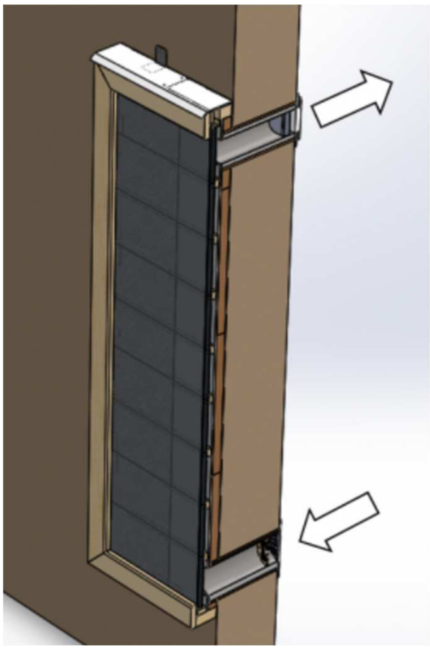


Fig 4: Panel air inlet and outlet - Image from the Wiki Enerlog

1- When the sun's rays come into contact with the panel's glass, they heat the slates through a greenhouse effect generated by the glass and the static first layer of air.

2- Between the slates and a wooden plate behind, at the bottom of the panel, air is introduced from inside the house.

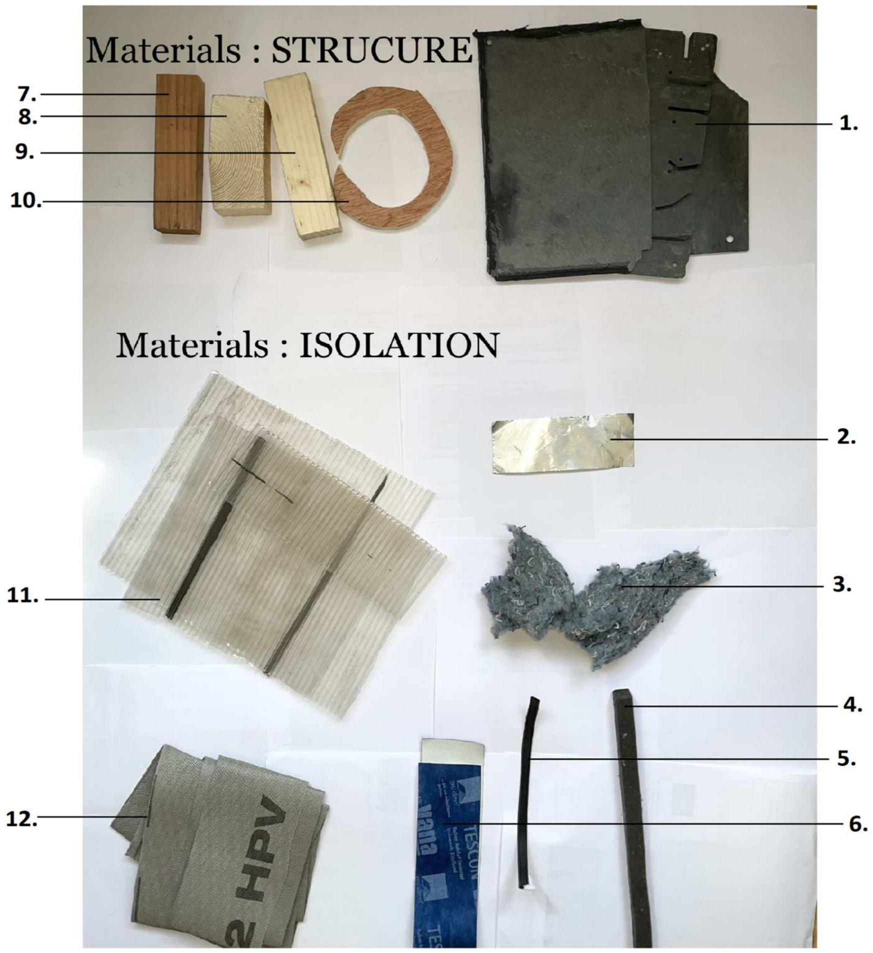
3- Through contact, the slates heat the moving air.

4- The warmed air is then reintroduced into the house at the top of the panel where it can reach up to 70°C.

THE MATERIALS WE USED:

In order to create our panel we try to use à maximum durable, local, recycled and accessible materials. As they were recycled we didn't have to pay to have them.

<u>The materials</u>:



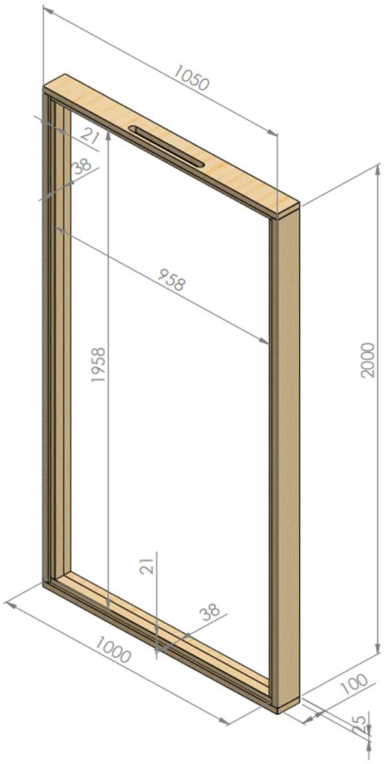
<u>LEGEND:</u>

1- Slate
2- Heat insulating aluminum tape
3- Recycled textile for insulation
4- Thermal adhesive foam
5- Gasket
6- Airtight tape
7- Wood used for the frame
8-9- Wood used for the baffle circuit
10- Wood used for the plywood plate
11- Cellular polycarbonate glass
12- HPV under roof screen

THE STRUCTURE:

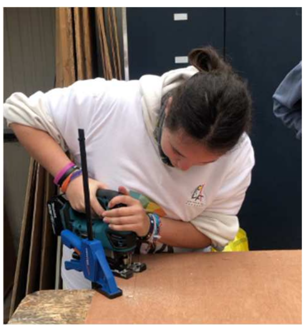
1- <u>The Frame</u>:

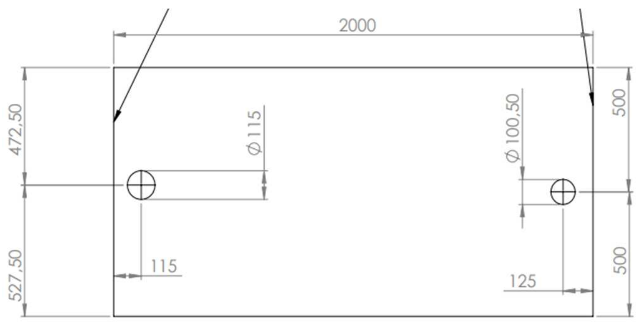
The frame (1,00 m x 2,00 m) is dimensioned to accommodate a cellular polycarbonate glass, a plywood plate, and a layer of recycled textile for insulation. To evacuate hot air outside the habitat during summer, an air outlet is drilled through the top rafter and batten.



2- <u>The plywood panel</u>:

The plywood installation stiffens the entire panel and is placed in the frame and secured. Two holes are drilled in the plywood for the air inlet and outlet. A pipe will be connected to the top hole, while the fan will be connected to the bottom.





3- The chicanes circuit :

The air circulating behind the slates bypasses wooden chicanes that have been placed to increase the air's residence time in the collector, thereby increasing heat exchange. The chicanes are fixed on the plywood wall.

4- The air inlet and outlet:

Two pipes were printed with a 3D printer by the ENERLOG engineer and disposed at the top and the bottom of the plywood panel.

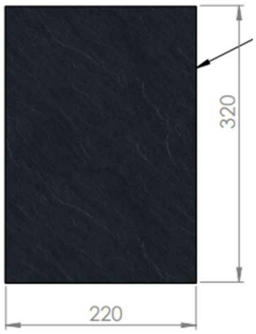
The air enters the panel from the bottom at ambient room temperature (~18°C in winter). It warms up on contact with the slates and is reinjected into the house through a high hatch. The hot air reaches a temperature between 30°C and 60°C depending on the weather and the amount of sunshine outside.

5- The slates:

The first layer of air is static and trapped between glass and slates (absorber). The greenhouse effect allows the black slates to increase in temperature. This mechanism is mainly governed by heat exchanges in the form of thermal radiation.

The slates act as an absorber by capturing about 89% of the energy flux. Therefore, 11% of the energy flux is reflected back to the glass.

In addition, there is a flux of infrared radiation emitted from the slate towards the absorber. The glass only allows a small portion of this energy flux to pass through and traps the heat.




6- The window:

The window has a high coefficient of transmissivity (90% for glass, 65% for cellular polycarbonate) and thus allows a large part of the solar radiation to pass. We chose a cellular polycarbonate window as it is lighter and cheaper.

89% of these radiations going through the window will be absorbed by the slates, the remaining 11% are reflected to the window trapping them again and acting like a greenhouse.

But there are also heat losses by conduction and convection through the glass between the trapped hot air and the outside air.


7- <u>The insulators</u>:

Behind the plywood plate, insulation made of recycled textile is used to limit heat loss through the back of the panel. Other insulators are also placed like aluminum tape, to reduce the heat loss or airtight tape to increase the panel tightness.

8- <u>Sensors and microcontroller</u>:

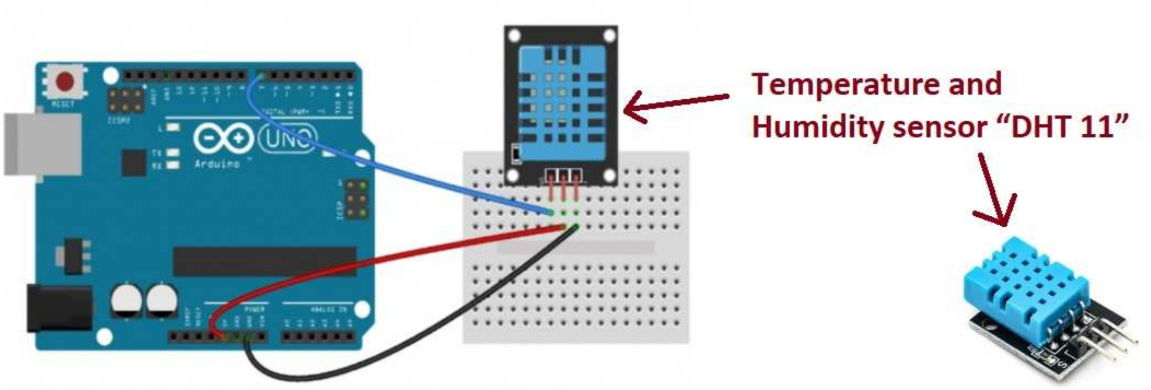
Although the aerosol panel is “Lowtech”, it is still recommended to add a little bit of electronics to maximize its performance. Indeed, for the panel to be more efficient, it is preferable to install ventilation so that the air can circulate more easily and in greater quantity in the panel.

We used an anemometer to measure and compare the speed of the air circulating inside our panel. It allowed us to test the tightness of our panel.

A sensor for temperature and humidity is placed at the top of the panel, when the expected values reach the values needed, the ventilation is activated.

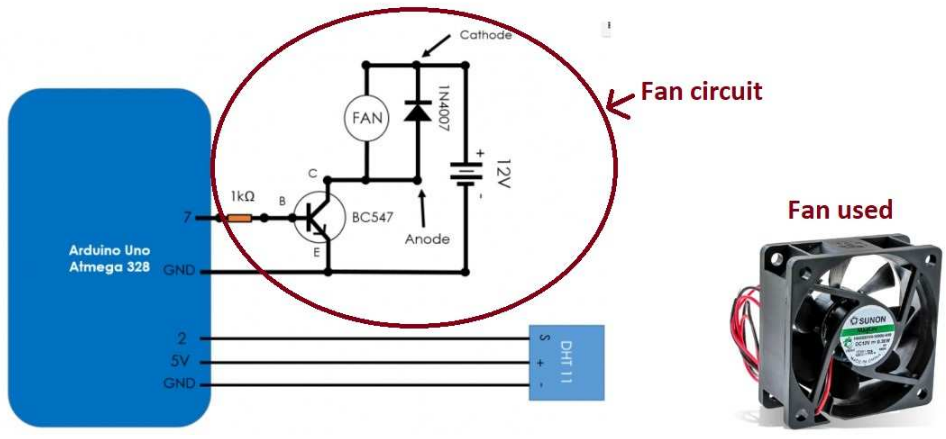
The user will be able to control the fan according to the temperature of the panel with the help of an electronic microcontroller board (Arduino for example).

Here we can see the diagram of the temperature and humidity sensor "DHT 11" connected to the Arduino microcontroller.



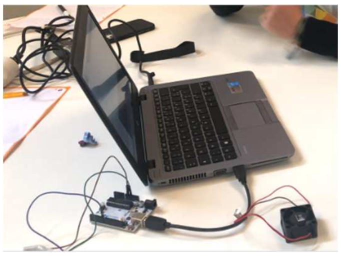
- The signal pin "S" must be connected to a digital pin number, here "2", of the Arduino board.
- The negative "-" pin must be connected to the mass (GND) of the Arduino board.
- Finally the positive "+" pin is connected to the 5V supply of the Arduino board.

If we add a fan for the air ventilation, a transistor and a diode should be added too.



Indeed, when the temperature expected is reached, a signal from the Arduino board is sent to the transistor connected to the digital pin "7". The transistor will then allow electric current to flow through the fan and activate its motion.

Our instructors from ENERLOG showed us how, with a simple code, it is possible to control the fan of the ventilation when the adequate temperature and humidity are reached.

We used the ARDUINO script below on the Arduino integrated development environment:

```
#include <DHT.h>
#define DHTPIN_1 2    // what digital pin we're connected to with the DHT 11 sensor
#define DHTTYPE DHT11   // activate the humidity and temperature sensor DHT 11
#define fan 7    // activate the fan at the digital pin 7

int maxTemp = 25; Threshold temperature that we define to activate the fan

DHT dht_1(DHTPIN_1, DHTTYPE);

void setup() {
 pinMode(fan, OUTPUT);   // output signal to activate or not the fan

 Serial.begin(9600);
 dht_1.begin();          // Switch on the DHT11 sensor
}


void loop() {
 delay(5000);   // Wait 5 seconds between each measure.
 // Read temperature and humidity (Reading time>250ms)
```

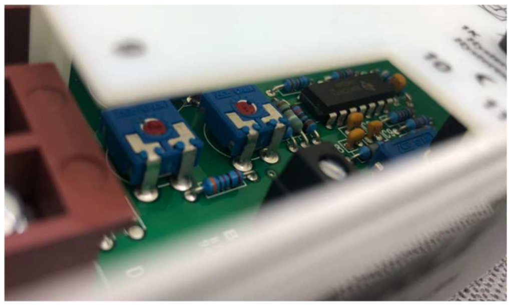
```
// Capteur #1
float h_1 = dht_1.readHumidity();     // Relative humidity
float t_1 = dht_1.readTemperature();  // Relative Temperature in degrees Celsius

// Activate/Deactivate the fan
if(t_1 > maxTemp) {
   digitalWrite(fan, HIGH);
} else {
  digitalWrite(fan, LOW);
}

Serial.print(" Humidity #1: ");  // The command "Serial.print" is used to communicate the values
Serial.print(h_1);
Serial.print(" %\t");
Serial.print("Temperature #1: ");
Serial.print(t_1);
Serial.print(" *C ");
}
```

Thank to this Arduino script, the fan will be activated when the temperature expected from the DHT11 sensor is reached.

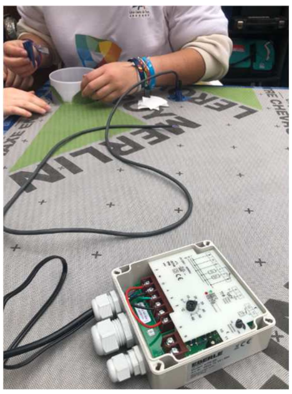
We will see appearing, in the communication window of the interface, the relative values of temperature and humidity measured by the DHT11 sensora appear.

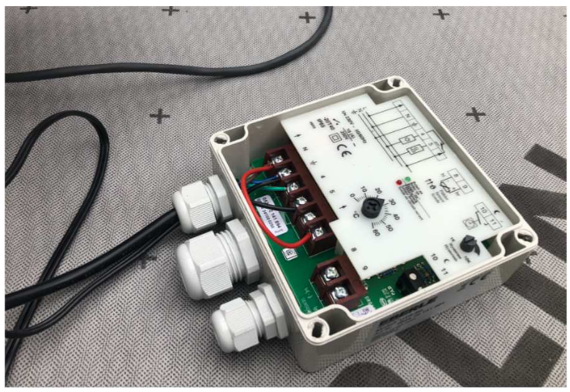
9- <u>Adaptation to our needs</u>:

However, for reasons of convenience, as we wish to use our panel for demonstration and quickly adapt the temperature expected with a cursor, we have equipped our aerothermal solar panel with a temperature regulator that can be found on the market.



As we can see, the temperature regulator found on the market also contains a microcontroller.

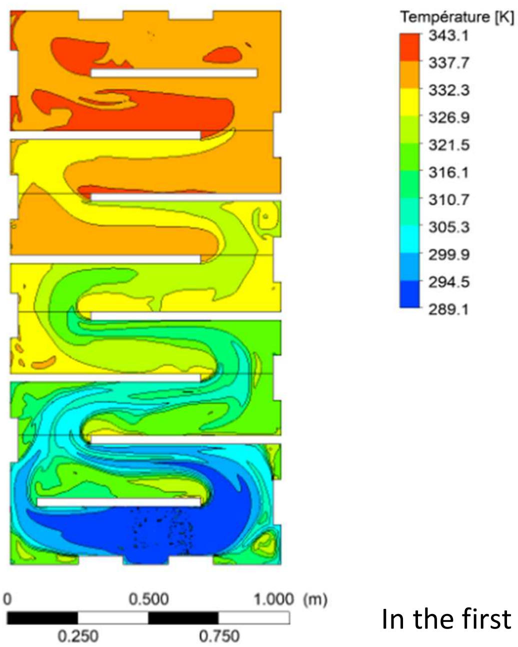




AIR CIRCULATION:

<u>First of all, what is expansion</u>?

The expansion is the augmentation of a body's volume because of the temperature difference. In the gas's case, its volume will increase when the temperature increases too, this will be called the gas expansion.

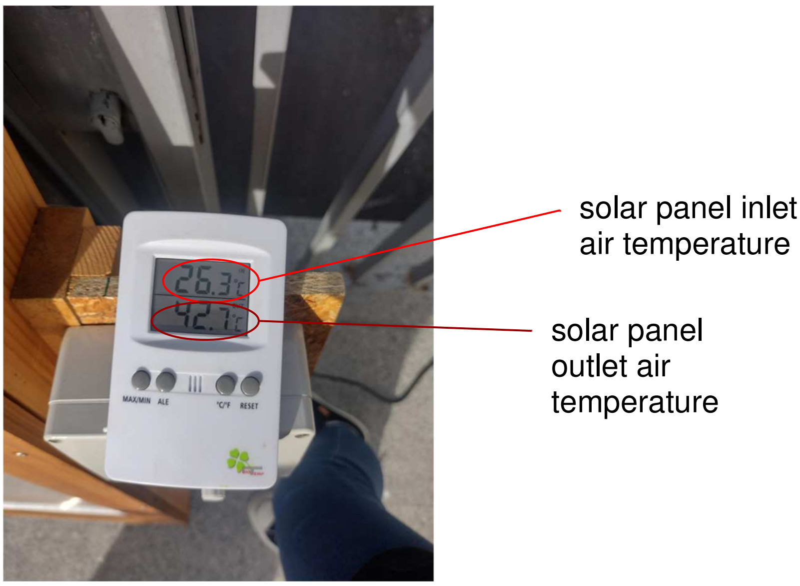


When the sunlight hits the slates, the photons disturb the particles which provoques a thermal energy. This energy will warm up the air .

The expansion makes the air go up.

In the first test performed in Andorra we proved that we can gain 17ºC, on a sunny day of winter, after 30 minutes of use.

$$\Delta T = T2 - T1$$



PROBLEM: IS OUR AEROTHERMAL SOLAR PANEL ADAPTED TO THE ANDORRAN CLIMATE?

After the construction of the aerothermal solar panel, we wished to know if our solar panel was adapted to the climate in Andorra. For that we needed to calculate two values:

1- <u>The heat loss of the habitat in Watts</u>: **P_{dep} = G x V x (Tint - Text)**

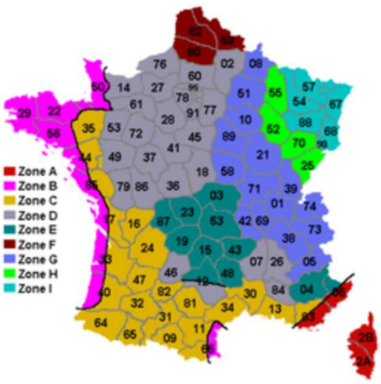
- **G** represents the heat loss coefficient in W/m³.°C of a building.

Created in 1974 by a reglementation, this value depends on the insulation level of the building and its date of construction.

<u>TABLE</u> :

Very well insulated (since 2012) : 0.6 W/m³.°C
Well insulated (from 2005 to 2012) : 0.65 W/m³.°C
Insulated (from 2000 to 2005) : 0.8 W/m³.°C
Moderately insulated (from 1990 to 2000) : 1 W/m³.°C
Poorly insulated (from 1974 to 1990 or renovated) : 1.4 W/m³.°C
Not insulated (before 1974) : 2 W/m³.°C

- **V** represents the volume of the room in m³.
- **Tint** represents the interior temperature of the habitat in °C, 18°C is usually the reference.
- **Text** represents the exterior temperature of the habitat in °C.



Altitude	Zone (voir carte)								
	A	B	C	D	E	F	G	H	I
0 à 200m	-2	-4	-5	-7	-8	-9	-10	-12	-15
201 à 400m	-4	-5	-6	-8	-9	-10	-11	-13	-15
401 à 600m	-6	-6	-7	-9	-11	-11	-13	-15	-19
601 à 800m	-8	-7	-8	-11	-13	-12	-14	-17	-21
801 à 1000m	-10	-8	-9	-13	-15	-13	-17	-19	-23
1001 à 1200m	-12	-9	-10	-14	-17		-19	-21	-24
1201 à 1400m	-14	-10	-11	-15	-19		-21	-23	-25
1401 à 1600m	-16		-12		-21		-23	-24	
1601 à 1800m	-18		-13		-23		-24		
1801 à 2000m	-20		-14		-25		-25		
2001 à 2200m			-15		-27		-29		

Value for Andorra : -14°C

If we want to know the winter heat loss of the habitat, we need to use the winter DJU (Degré de Jour Unifié).

The winter DJU represents the average level of temperature difference between the outside and the inside of the habitat during the winter period (213 of heating days, from the 1st october to the 1st may).

There is the formula : **(Tint - Text) = DJU / 213**

As we can read on the map of France before, Andorra in located in zone C, between 1 800m and 2 000 m of altitude. The DJU here in Andorra is equal to : **-14°C**

Now, we use the formula: $$P_{dep} = G \times V \times (Tint - Text)$$

- **G = 1,4 W/m³.°C**
  The constant of a poorly insulated buildings from 1974 to 1990, that represents a certain quantity of buildings in Andorra.
- **V** = 37 m² x 2 m = **74 m³** A basic room size with a area of 37 m² and a height of 2 m.
- **(Tint - Text)** = **14°C**

P_{dep} = 1 450.4 watts

To know the energy lost **E_{dep}** over a day and over a winter, this power **P_{dep}** must be multiplied by 24 hours and by 213 days.

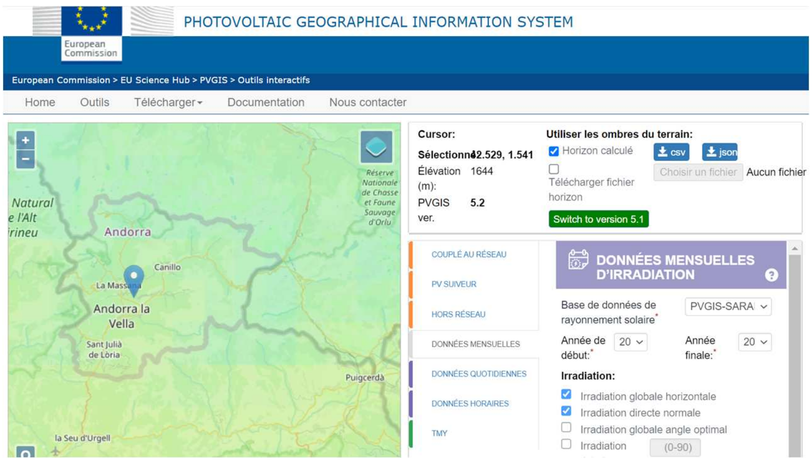
E_{dep} = 1 450.4 X 24 X 213 **= 7 414.4 kWh**

2- <u>The potential Energy of the panel</u>: **E_{panel} = I** x **R** x **S**

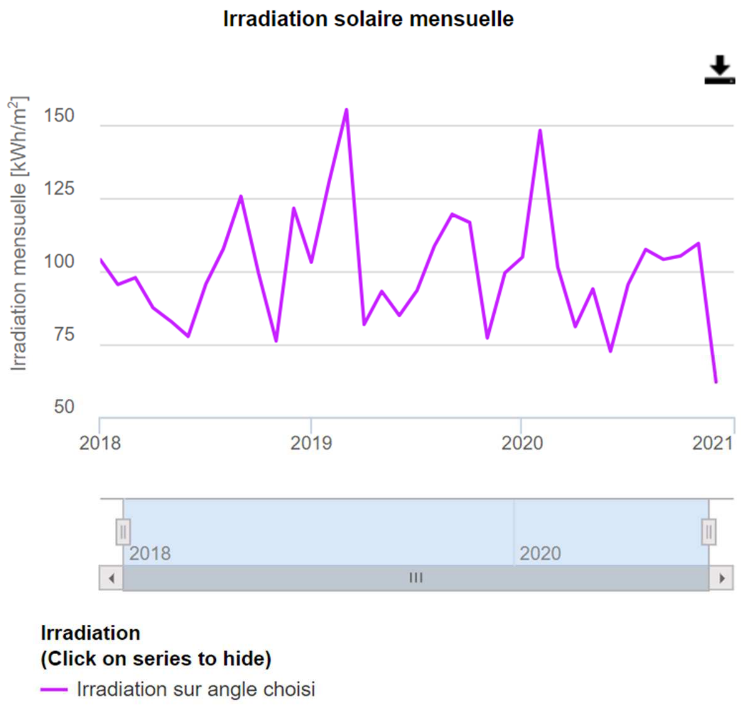
It represents the energy that the panel is able to give in our location.

- **I** represents the level of irradiation in a located place in kWh/m²
- **R** represents the yield of the panel, here we use a yield of 50% for our panel
- **S** represents the area of the panel in m²

First, to find the winter level of irradiation **I** in Andorra, we used the website "Photovoltaic Geographical Information System" : https://re.jrc.ec.europa.eu/pvg_tools/fr/



By locating Andorra on this website, we obtained the following graph and found out that the irradiation of Andorra strongly depends on the month of the year.
The values were situated above 100 kWh/m² from December to March.



We also extracted an Excel file with monthly data of the level of irradiation in Andorra from 2018 to 2020:

1	Latitude (decimal degrees):42.529
2	Longitude (decimal degrees):1.541
3	Radiation database:PVGIS-SARAH2
4	
5	yearmonthH(i)_mT2m
6	2018Jan103.93-2.3
7	2018Feb95.44-5.6
8	2018Mar97.79-2.2
9	2018Apr87.53.0
10	2018May82.985.7
11	2018Jun77.7211.6
12	2018Jul95.5114.5
13	2018Aug107.6414.0
14	2018Sep125.5911.9
15	2018Oct99.315.6
16	2018Nov76.140.3
17	2018Dec121.510.5
18	2019Jan103.06-4.4
19	2019Feb130.290.1
20	2019Mar155.190.6
21	2019Apr81.81.9
22	2019May93.125.3
23	2019Jun84.8813.3
24	2019Jul93.3415.7
25	2019Aug108.6915.0
26	2019Sep119.4511.2
27	2019Oct116.657.8
28	2019Nov77.17-2.0
29	2019Dec99.420.3
30	2020Jan104.84-1.1
31	2020Feb148.161.5
32	2020Mar101.470.4
33	2020Apr81.034.1
34	2020May93.959.3
35	2020Jun72.5910.3
36	2020Jul95.4714.7
37	2020Aug107.413.7
38	2020Sep104.029.3
39	2020Oct105.253.9
40	2020Nov109.472.7
41	2020Dec61.95-3.2

H(i)_m: Irradiation on plane at angle (kWh/m2/mo)
T2m: 24 hour average of temperature (degree Celsius)

PVGIS (c) European Union, 2001-2023

Then we used and Excel table to calculate:

- The average monthly solar irradiation over these three years
  ex: E9 = MOYENNE(B9:D9)
- The average solar irradiation that a panel located in Andorra can receive over the period from October to March.
  ex: B17 = SOMME(E9:E15)

	A	B	C	D	E
1	Emplacement	Andorre la Vieille			
2	Latitude	42,507			
3	Longitude	1,524			
4	Angle d'inclinaison	90			
5					
6	**Irradiation solaire mensuelle (kWh/m²)**				
7	Mois	2018	2019	2020	Moyenne
8					
9	Jan	*103*	*103*	*104*	103
10	Feb	*95*	*130*	*148*	124
11	Mars	*97*	*155*	*101*	118
12	Avril	*87*	*81*	*81*	83
13	Oct	*99*	*116*	*105*	107
14	Nov	*76*	*77*	*109*	87
15	Dec	*121*	*99*	*61*	94
16					
17	Irradiation solaire du capteur (kWh/m²) hiver	716			

We find out that :

- The level of irradiation in Andorra is **I = 716 kWh/m²**

The surface **S** of our aerothermal solar panel is **S** = 1 m x 2 m = **2 m²**

We can now calculate : **E**panel = I x R x S = 716 x 0.5 x 2 = **716 kWh**

3- <u>Analisis:</u>

The panel should represent 30% of the heating needs of a habitat because it is not recommended to rely entirely on this type of device to heat an entire room.

If we compare the Energy heat loss of the habitat **Edep = 7 414.4 kWh** with potential Energy of the panel **Epanel = 716 kWh**

We can calculate the number of panels needed for a room with a volume of **V** = 37 m² x 2 m = **74 m³**

Number of panels = 7 414.4 x **0.3** / **716 = 3.1 panels**

CONCLUSION :

Andorra is a small mountainous country with great potential in terms of solar resources; Indeed, this territory has strong sunshine throughout the year. Installing this type of panel can allow users to constantly keep their homes at a pleasant ambient temperature. However, this is only possible if the accommodation is very well insulated.

Indeed, it was possible for us to calculate what panel surface would be needed to heat 30% of a room in Andorra.

To conclude, we found that one aerothermal solar panel with a surface of 2 m² is not enough to compensate for the loss of heat from a 37 m² room of a poorly insulated building in Andorra.

We must first obtain a good insulation of our home before installing an aerothermal solar panel in order to maintain the heat given by the panel inside the room.

PERSPECTIVES:

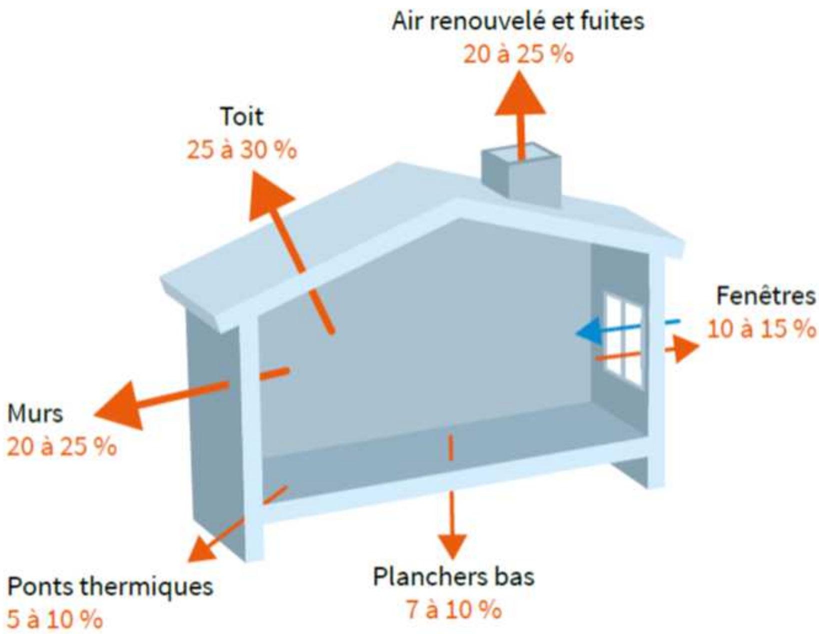
What can be done to improve the aerothermal solar panel efficiency?

Many parameters come into play:

- The inclination of the panel with the sun orientation to increase the amount of radiation coming into the panel
- The volume of the room
- A better insulation of the panel to reduce the loss from its window and structure.

But, the first improvement should be good insulation of the house.

The picture below, from the ADEME website (Agence de l'environnement et de la maîtrise de l'énergie), represents the main sources of heat loss in a home and where it is possible to act in order to reduce the heat loss : the wall, the roof and the ventilation.



ACTIONS IMPLEMENTED:

Our objective is to share our project with others, to inspire the use of the aerothermal solar panel and to promote the low-technologies.

For that, we created an Instagram account to promote and share our project :

@1ere_se_panneau_aerosolaire

We will soon present the aerothermal solar panel to the organizations that supported us in order to promote this technologie : FEDA, HERACLES and ROTARY CLUB ANDORRA

We will also give a presentation of our aerothermal solar panel in front of visitors at the FEDA Museum of Electricity in order to reach a new audience.

SOURCES:

ENERLOG Website: https://www.enerlog.fr/chauffage-enerlog/

Photovoltaic Geographical Information System Website: https://re.jrc.ec.europa.eu/pvg_tools/fr/

Définition du Degré Jour Unifié (DJU): https://fr.wikipedia.org/wiki/Degr%C3%A9_jour_unifi%C3%A9#:~:text=Le%20degr%C3%A9%20jour%20unifi%C3%A9%20(DJU,la%20chaleur%20de%20l'%C3%A9t%C3%A9.

THANK YOU VERY MUCH FOR YOUR INTEREST IN OUR PROJECT