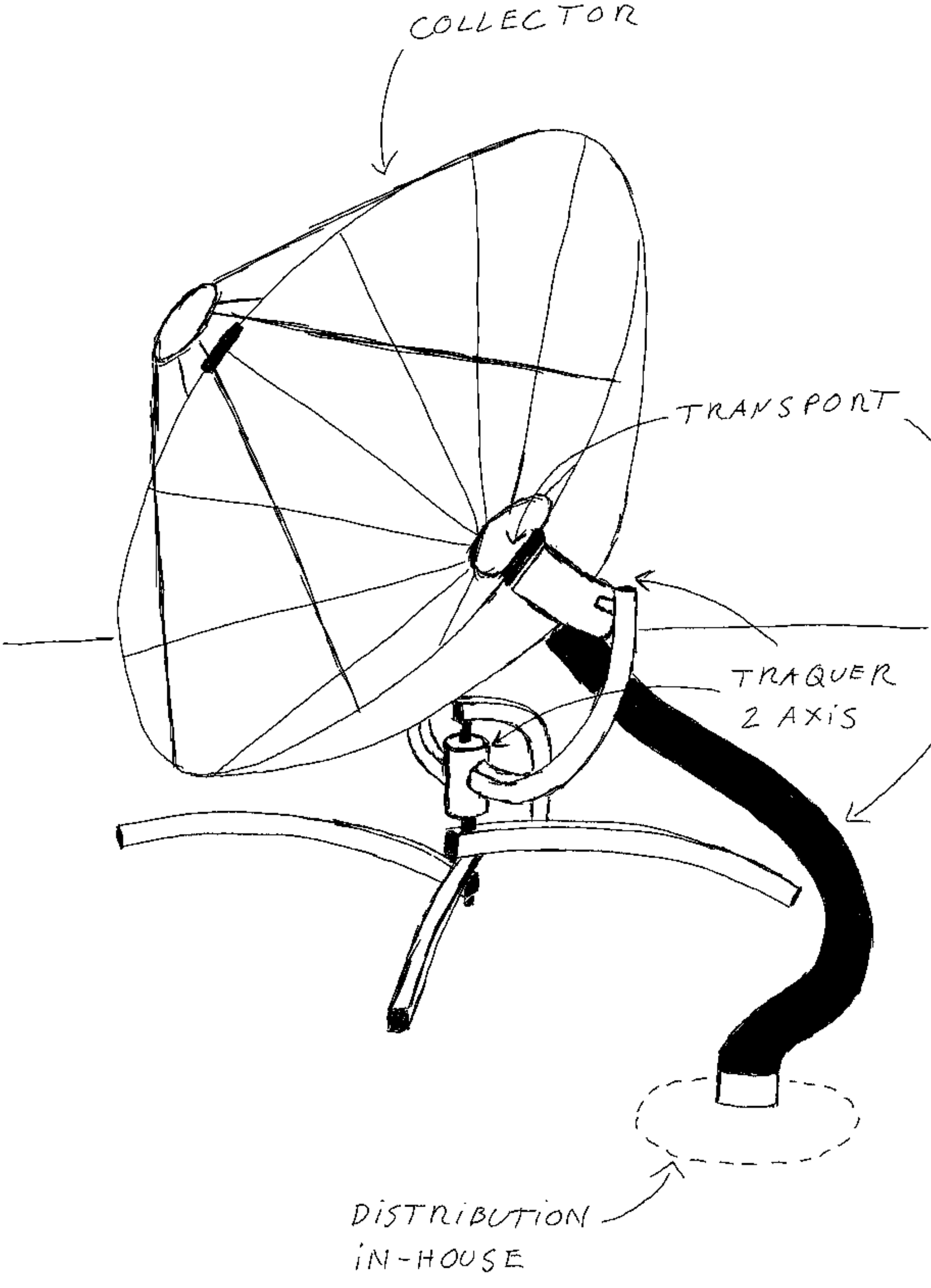
THE SUN HEATER



1. Challenge addressed

1.1 **Biggest energy consumption in EU:**

In 2019, in Europe, 63.6% of the house's energy consumption was related to space heating, 24.2% was covered with non-renewable natural gas and 17.7% from renewable and wastes, meaning resources burning (wood / waste)

Share of fuels in the final energy consumption in the residential sector by type of end-use, EU, 2019
(%)

	Total Residential /Households	Space heating	Space cooling	Water heating	Cooking	Lighting and appliances	Other end uses
Electricity	24.7	3.4	0.4	3.0	3.0	14.1	0.8
Derived Heat	8.3	6.4	0.0	1.9	0.0	0.0	0.0
Gas	32.1	24.2	0.0	6.1	1.9	0.0	0.0
Solid Fuels	2.9	2.6	0.0	0.2	0.0	0.0	0.0
Oil & Petroleum Products	11.8	9.2	0.0	1.7	0.8	0.0	0.1
Renewables and Wastes	20.1	17.7	0.0	1.9	0.3	0.0	0.1
Total	**100.0**	**63.6**	**0.4**	**14.8**	**6.1**	**14.1**	**1.0**

Source: Eurostat (online data code: nrg_d_hhq)

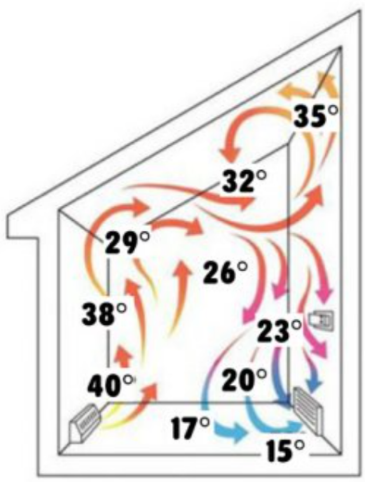
eurostat

Source: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households

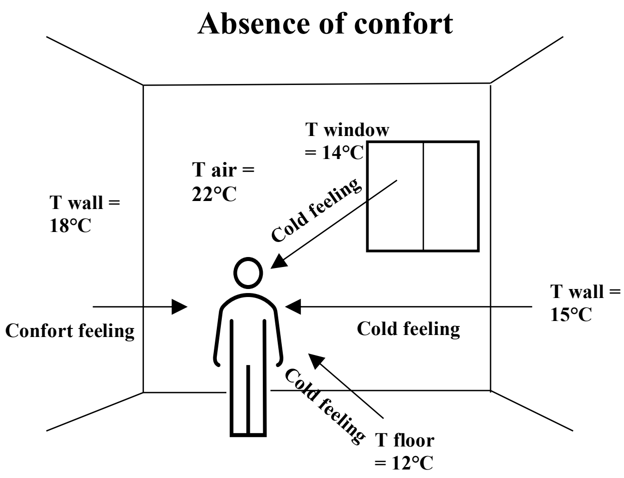
1.2 Today's solutions:

In parallel to this fact, today most heating solutions rely on the physical principle of convection which occurs when heat is carried away from the heated element via moving air.

However, convection is not the most efficient solution for space heating, the phenomenon of heat stratification in the air induces energy over-consumption without managing to homogeneously heat the space, which brings a bad thermal comfort.

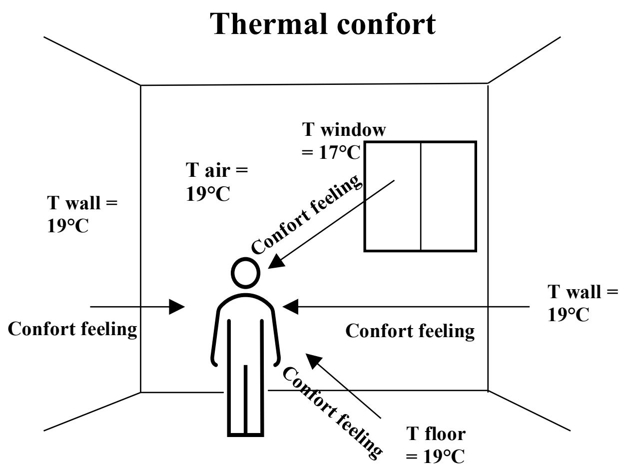


Temperatures on °Celcius



Space not homogenously heated. T on °Celcius

This effect is partially counterbalanced by the radiation power (infrared radiation) of the heating systems themselves. Pushing this logic further, new heating systems called long-range infrared (IR-C) heaters, are emerging.



Space homogenously heated. T on °Celcius

1.3 Heating and energy:

Whatever the solution, heating is an energy-intensive activity.

Heating system	**Surface temperature**	**% Radiation**
Wall convector	...	5% à 10%
Radiant ceiling panel	around 300°C	15% à 25%
Low-temperature radiator	Less than 90°C	35% à 45%
Low-temperature heating floor	maximum 28 °C	50%
Heating wall	around 40 °C	around 60% surface dependent
Low-temperature heating ceiling	aroung 40°C	70% à 80%
Long-range infrared radiators	Less than 90°C	Up to 90%

As showed earlier, most of the heating energy source comes from combustion (gas, wood, waste) because they produce an important amount of energy which can be directly used for heating, but at the same time they release greenhouse gases.

We've also seen that today's most energy-efficient electricity-based heating solution (low carbon or not depending on electricity production) are the radiation heaters.

However, this solution is still energy-intensive relatively to other uses of electricity in a household. To get the magnitude of the energy required to heat a space we can rely on the recommended power (Watts/m²) for heating:

	Recommended power (Watts/m²) depending on the technology used and level of thermal insulation with the best-in-class heaters in its category.	
Space to heat	Convection heaters: level of insulation [**excellent** / good / average / **bad**]:	Radiation heaters (infrared):
Living-room, Dining room, Kitchen, Office, Toilets (A.h.t 21°C)	[**80 Watts/m²** to **110 Watts/m²**]	[**45 Watts/m²** to **75 Watts/m²**]
Bathroom (A.h.t 22°C)	[**85 Watts/m²** à **120 Watts/m²**]	[**50 Watts/m²** à **70 Watts/m²**]
Bedroom (A.h.t 19°C)	[**75 Watts/m²** à **90 Watts/m²**]	[**45 Watts/m²** à **60 Watts/m²**]

Values for the lowest temperature of the year for Paris (According to historical records). Notion defined by the norm NF EN 12831 called "température de base extérieure". A.h.t = Average heating temperature. Source : https://www.foxof.com/nombre-et-puissance-radiateurs-electriques/

Even though these values appear as "low", a 30m² space would require (to simplify we will use 80 Watts/m² as the average): 30 m² * 80 Watts/m² = 2.4 kWatts of electrical power.

Considering a program of 5 hours heating per day, the monthly energy consumption for such space would be 2.4kWatts * 5 hours * 31 days = 372 kWh.

In order to have a global end-to-end system efficiency we must consider the end-to-end electricity use efficiency, from production to the electrical outlet: 34,22% in Europe.

Energy source	Efficiency	Efficiency (best case scenario)	Energy transportation and distribution	From production to house electrical outlet efficiency	Europe energy mix	Global Europe electricity production efficiency
Thermal power plant (coat, petrol)	35% to 40%	40%	6%	34,00%	13,20%	34,22%
Flame power plant (gas)	Up to 40%	40%		34,00%	19,70%	
Nuclear	30%	30%		24,00%	24,80%	
Hydraulic	80%	80%		74,00%	12,70%	
Wind power(1)	Up to 25% (onshore) and Up to 35% (offshore) (1)	30%		24,00%	14,40%	
Photovoltaic	22% (Best in the market today)	22%		16,00%	5,20%	
Other (biomas, ..)	NA	40%		34,00%	10%	

(1)For wind power these values represent the % of availability of the production
Annexed documents in project files « SunHeater System Dimensioning.excel »section "Electricity Prod Efficiency"
Source 1: https://www.irdeme.org/Bilan-quantitatif-des-modes-de-production-d-energie-electrique-1619
Source 2: https://www.connaissancedesenergies.org/questions-et-reponses-energies/electricite-combien-selevent-les-pertes-en-ligne-en-france#:~:text=Sur%20le%20r%C3%A9seau%20de%20transport%20d'%C3%A9lectricit%C3%A9%2C%20le%20gestionnaire%20RTE,(20%20TWh%2Fan).
Source 3 : https://www.connaissancedesenergies.org/le-mix-electrique-de-lunion-europeenne-en-2020-220218

2. How does this project alleviate this problem?

Considering:

- The use of infrared as an energy-efficient heating solution.
- Today's low end-to-end low-carbon-electricity-based heating system efficiency.
- Today's solution high RUN cost (due to energy cost and energy-intensive need for heating).

Our proposition is to:

- Directly use solar radiation (infrared) energy as a heating solution through a parabolic capture system (all spectrum, especially infrared).
- Captured directly "onsite", which increases end-to-end system efficiency (no transport).
- Guided and propagated inside the house.

We will call this system further in the document: **SunHeater**

2.1 Evaluating the interest of the SunHeater

Taking as an example the city of Toulouse (South France).

- Input data:
  - The average recommended power (per m2) with today's most efficient electricity-based heating solution
  - The amount of available radiation (source for the year of 2020)
  - A SunHeater end-to-end solution efficiency hypothesis of 80%

- Use Case (specifications)
  - A space to heat of 30m2
  - A target of 100% heating needs coverage from the month of March

The analysis gives the following results (formulas available on the excel file joined to the project):

									System dimensioning for a given space	
									Space to heat (m2)	30
Month	H(i)_m	Days	SunHeater efficiency	SunHeat System output for each 1m2 Sun input	Recommended power (Watts/m²)	Average Heating time per day (hours)	Energy consummed per m2	SunHeat heating coverage in m2 for 1m2 of Sun input	Required sun input for the system (dimensionned for production peak) in m2	SunHeat heating need % coverage
January	86900	31		69520	80	5	12400	5,606451613		51%
February	120670	28		96536	80	5	11200	8,619285714		78%
March	170220	31		136176	80	5	12400	10,98193548		100%
April	200700	30		160560	40	5	6000	26,76	2,7317589	244%
May	211500	31		169200			0			
June	233550	30	0,8	186840			0			
July	253740	31		202992			0			
August	237990	31		190392			0			
September	202320	30		161856	40	5	6000	26,976		246%
October	155160	31		124128	80	5	12400	10,01032258		91%
November	104170	30		83336	80	5	12000	6,944666667		63%
December	87710	31		70168	80	5	12400	5,658709677		52%

Annexed documents in project files « Monthly in-plane irradiation for tracking system.pdf » and « SunHeater System Dimensioning.excel » data source « Monthly in-plane irradiation for tracking system.csv ». Source: https://re.jrc.ec.europa.eu/pvg_tools/en/
Source 2 (Recommended power): https://www.foxof.com/nombre-et-puissance-radiateurs-electriques/

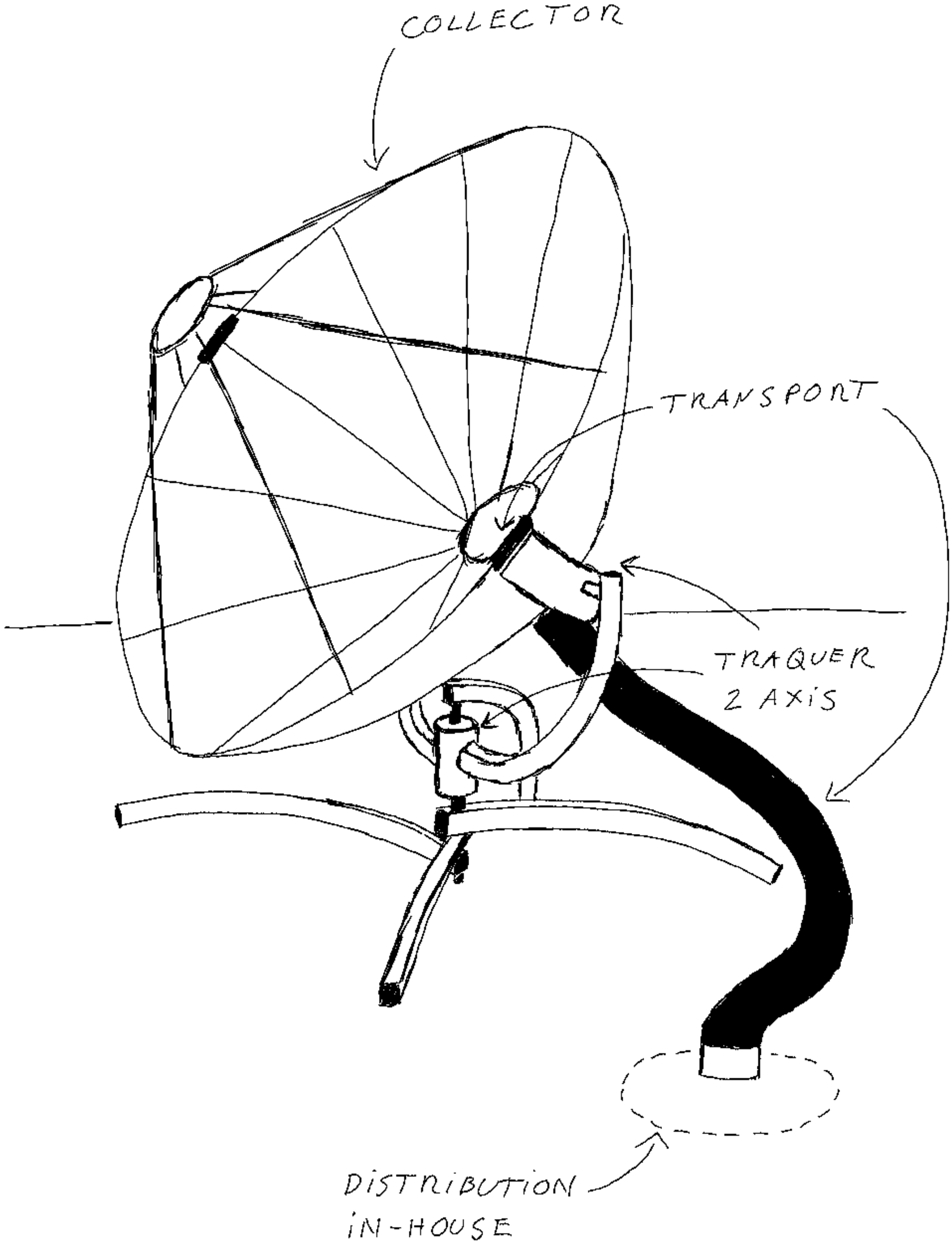
Analysis output:

- ⇨ The diameter of the required parabol would be = SQUARE(INPUT in m2 / PI)*2 = 1,864988863 meters
- ⇨ As for many sun-based solutions dimensioning to meet winter needs induces a production excess on summer (excess witch can also be used for other needs)

3. SunHeater Design overview

The solution is based on 4 sub-systems:

- The energy collector
- The energy transportation
- The 2 axis sun-tracking system
- The energy distribution inside the house



SunHeater design overview

3.1 The energy collector

The sun reflecting parabol is a very common, DIY plan available solution, widely known mainly as a sun-cooking solution.

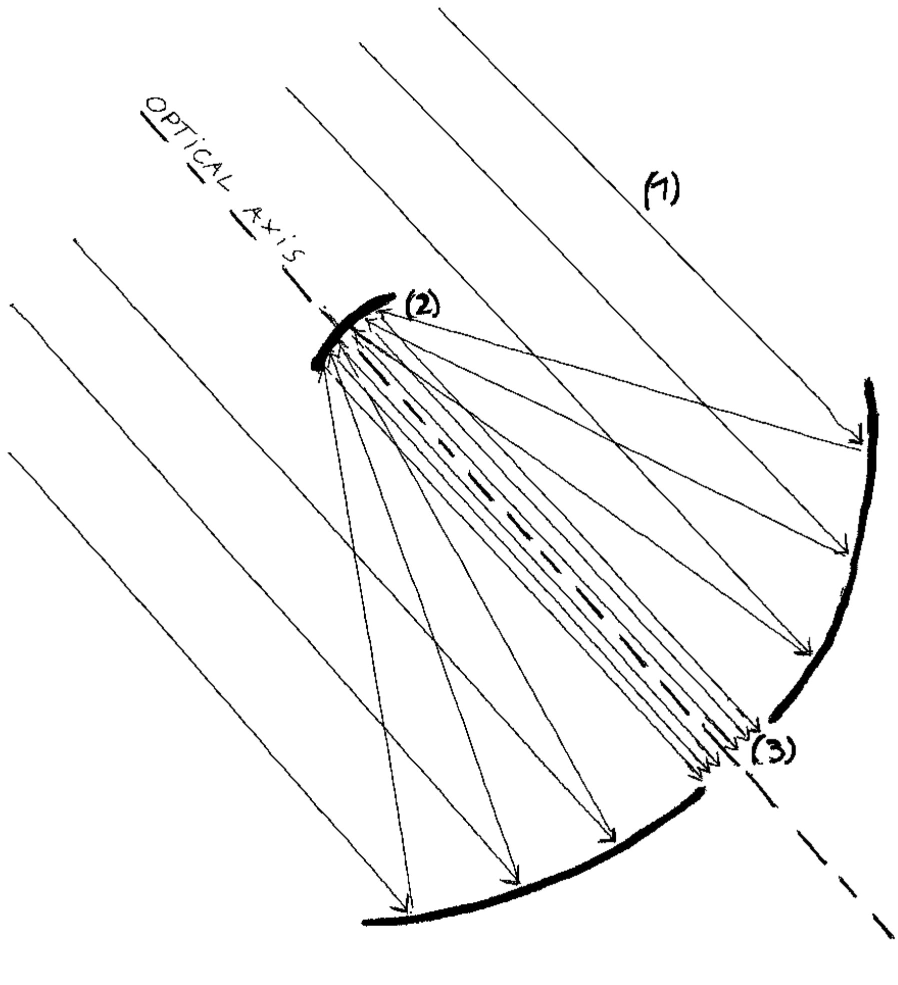
Today, it's easy to find on the market mirror-adhesive films presenting a high efficiency-reflecting rate > 90% for parabol's construction.

Using a parabol as a collector solution presents the advantage of concentrating, the sun radiation power on a small point, making it easier to transport elsewhere (inside the house in our case).

The system consists of a:

- One main parabol: for collecting the sun radiation and sending it to its focal point
- One secondary parabol: placed at the main's parabol focus point it sends the main parabol collected radiation back to the main's parabol summit where the transport system is located.

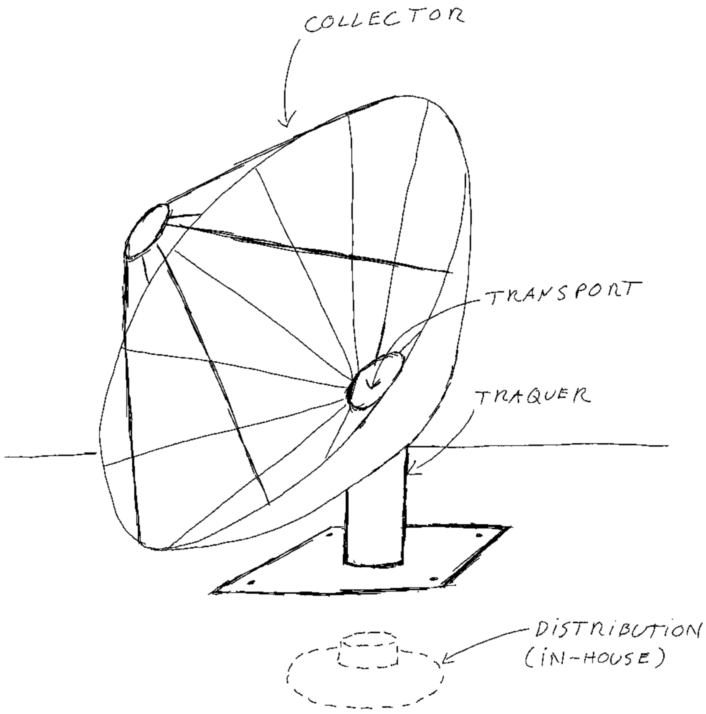
Such solution presents the interest of placing the concentrated radiation at a very simple collecting point AND having radiation rays arriving with an important incidence angle (close to 180°) to the transport system. This will be necessary for transportation which will rely on the principle of total reflection.



SunHeater parabol. 1: sun radiation, 2: sun radiation reflected, 3: sun radiation reflected back to the main's parabol summit for transport

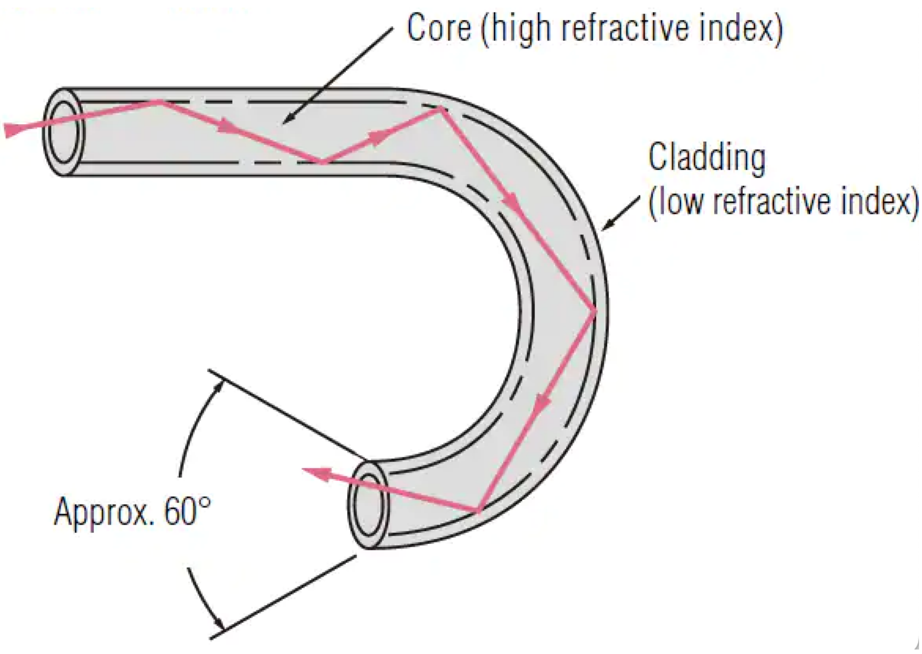
3.1 The energy transportation

The first solution to be imagined was a unique straight reflecting pipe from the parabol's summit to the in-house distribution conducing to the following design:



However, the rigidity of such system brings a constraint, the roof space availability at the very top of the in-house space to heat.

A more polyvalent solution would be to use a flexible cable transporting the radiation relying on the principal of internal total reflection. In other words, the optical fiber technology approach.



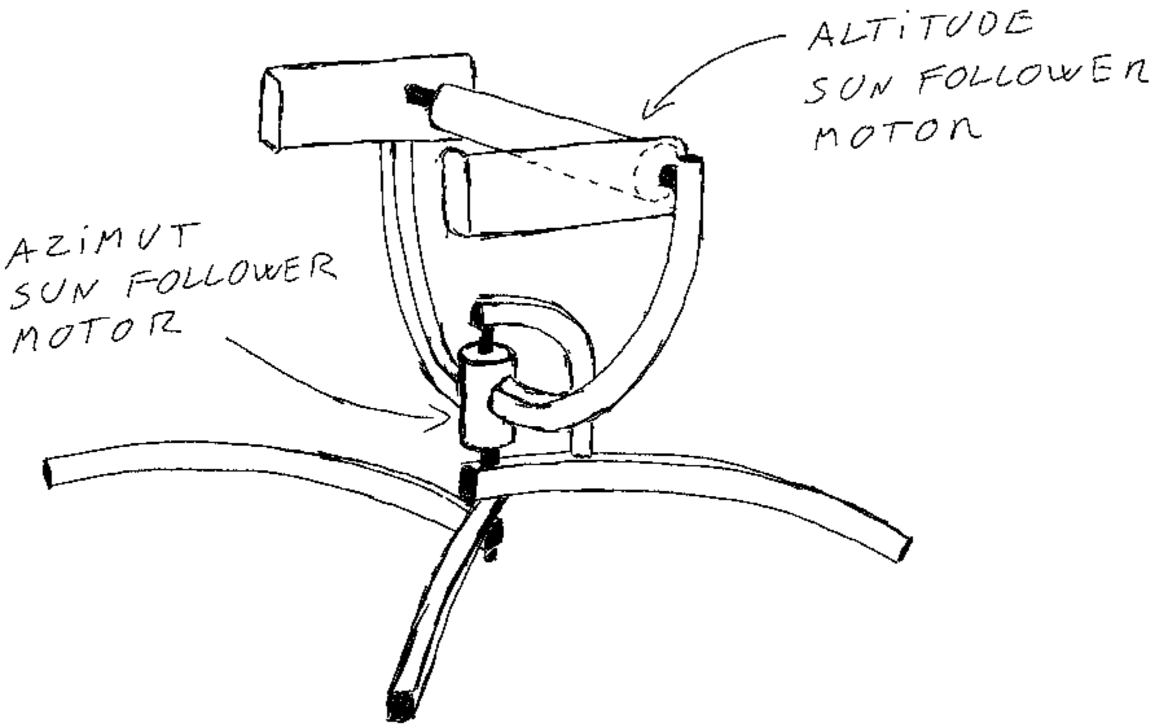
The materials allowing such total reflection for sunlight minimizing attenuation (absorption by the materials) is still to be determined and will be done during the prototype phase.

The good news is, taking into consideration the parabol design, the incidence angle is as high as possible, close to 180°, giving the maximum flexibility for the choice of the materials.

3.2 The sun-tracking system: to have the parabol always facing the sun

The sun tracking system consists of:

1. Two roller shutter/awning motors: These motors are industrial, easy to purchase, cheap, and with a high torque (10Nm being the lowest). Average price of each motor around 30€ new, they are also easy to find second hand.



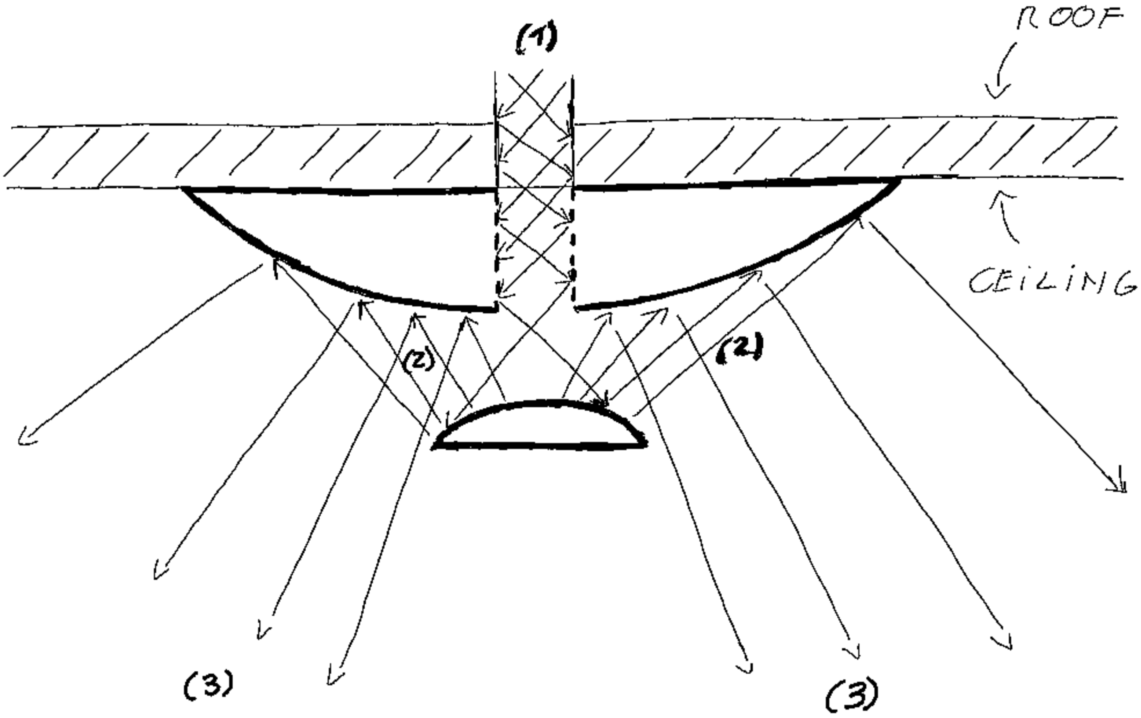
2. The sun tracking control will use two "single axis" solar tracking modules, each one controlling a relay connected to the parabol tracking motors.
    a. Average price of each tracking module 4€ (Example: the EC BUYING HD-36)
    b. Average price of each relay: 5€

3.3 The energy distribution inside the house

The energy distribution it's pretty much the opposite of the collector in terms of purpose of course, but also design!

The Solution consists of two pairs of convex reflecting surfaces (which we'll call "mirrors"), working with the same principle as the collector, but the other way around:

- Sun radiation arrives from transport to the distribution system (1)
- One small convex mirror receives the radiation from transport and reflects it to the main mirror (2)
- The main mirror receives the radiation and reflects it back to the room for heating (3)



SunHeater distribution. 1: sun radiation, 2: sun radiation reflected to the main mirror, 3: sun radiation reflected to the room for heating

It is to be noted that:

- The size of the distribution system (mirrors) is not related to the size of the collector (parabol). This is exclusively linked to the space between the two mirrors of the distribution system
- The dimensions of the main mirror are calculated based on the focal distance of the small mirror. This is necessary for avoiding radiation reflected back from the small mirror to "hit the ceiling"

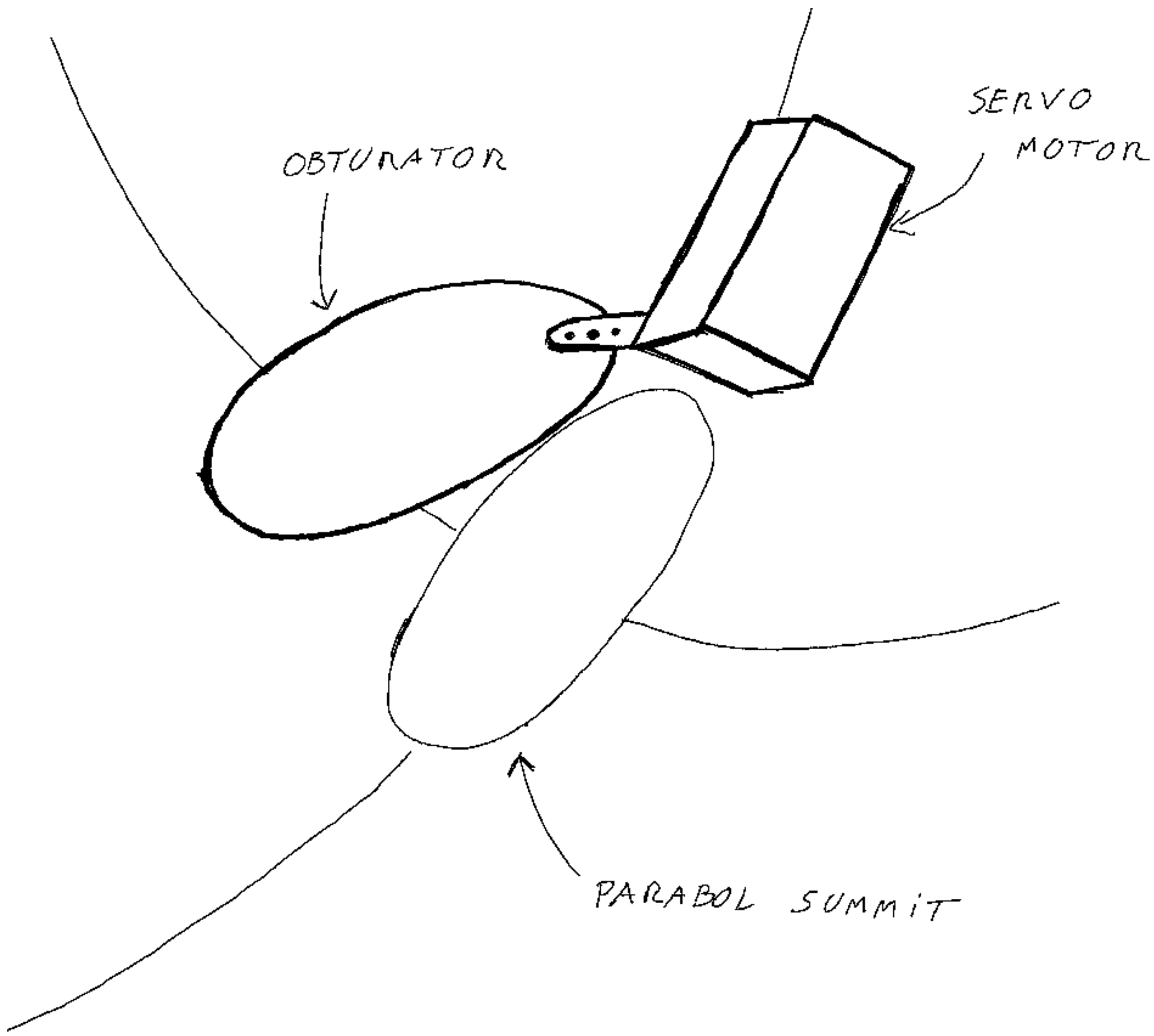
This design has the advantage of:

- Once again to be a DIY feasible solution, buildable using mirror-adhesive easy to find films with high efficiency-reflecting rate > 90%.
- It avoids direct radiation entering the room for safety.

3.4 Heat control

For controlling the radiation entering the transportation system we will use a servo motor.

The servo motor, which will be controlled from inside the house, will be able to let the radiation enter the transportation system's partially or entirely by obturating it's entry.



SunHeater radiation control at the back of the parabol

Servo motors are among most common and cheap motors on the market, they are widely used for robotics purposes and can be controlled with simple Pulse Width Modulation (PWM) using an Arduino board for example.

3.5 Energy excess

As showed earlier on section 2.1 (Evaluating the interest of the SunHeater), depending on the system's dimensioning there can be an energy availability excess, especially on the summer months on which no heater is required at all.

The collector system can then be used as energy source for other needs such as cooking!

A secondary project would be necessary to further explore this way but using sun energy from the collector could perfectly feed a hybrid electric-solar cooking appliance which will use solar energy whenever available and will complete with electricity for meeting the user's requested cooking power.

After buiding the SunHeater prototype next project will try to focus on this idea.