 en Français

# PHOTOVOLTAIC SOLAR WATER HEATER

# AND SWIMMING POOL HEATING

# WITHOUT BATTERIES, USING PTC CERAMIC HEATERS

**Design elements (**full lenght paper)

In the early years of the 21st century, it would have been provocative to put the terms "photovoltaic electricity" and "thermal energy" together because of the price of the panels. About fifteen years later, photovoltaic panels are establishing themselves as a very competitive energy source, among other things for the production of hot water. Moreover, hot water is a form of energy storage, and storage is essential in renewable energy.

The aim here is to propose some elements for the design of an electro-solar hot water production system.

This document follows on from the work of the small "photovoltaic-solar-cooking.org" team, to which reference will be made as far as necessary, in order to avoid unnecessary copying.

Translated with www.DeepL.com/Translator (free version)

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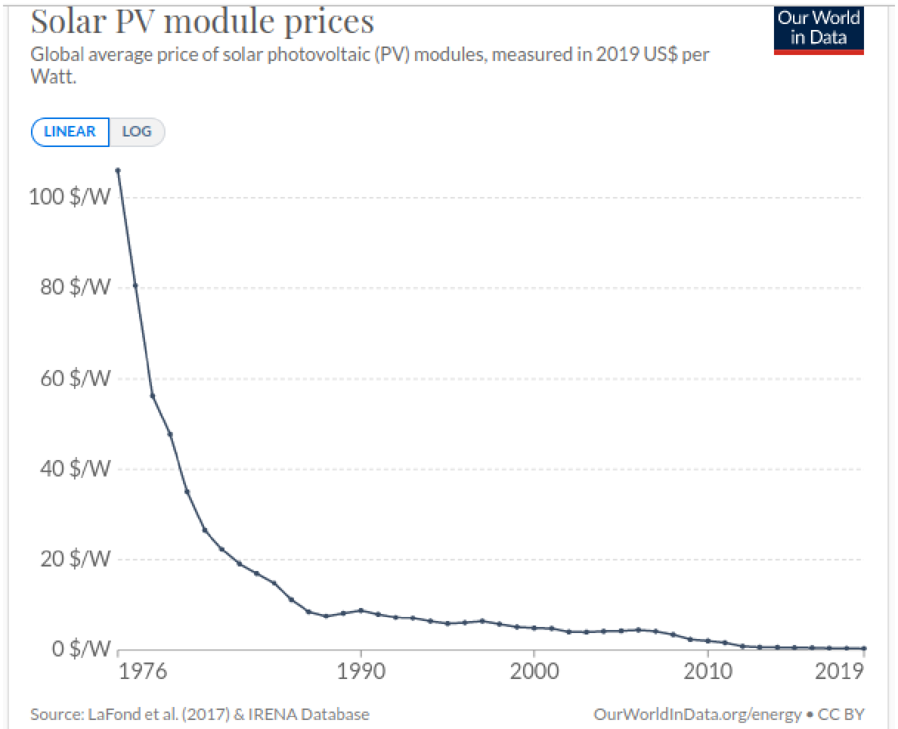


https://ourworldindata.org/search?q=solar+PV+modules+prices
for more précision, download the .csv file

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## 1 – THE CONSTRAINTS OF THE LAWS OF ELECTRICITY

Solar electric installations are subject to the same rigid laws of electricity as grid electricity installations, so it is prudent, as a first step, to review the constraints involved and their consequences.
Electricians will want to consider these few lines with indulgence, and could go directly to part 2.

**When it comes to producing heat from electricity,** the most commonly used method is Nickel-Chromium resistors, which can be found in many appliances, from toasters to domestic ovens, from convector heaters to hot water production.
There are other devices: microwave ovens, induction hobs, etc., but they are subject to the same constraints, which will be developed below: so let's avoid spreading ourselves too thin.

On all these devices there are several indications, in particular a voltage U (often: U = 230 Volts), a current I, for example I = 6 Ampere for an electric coffee machine or an iron, and a power P, which is the product of the voltage multiplied by the current, for example in this case: P = U * I = 230*6 = 1380 Watt. We can also deduce that the R value of the heating resistor inside the iron, i.e. its capacity to oppose the passage of the electric current, is equal to R = U/I = 230/ 6 = 38.33 Ohm.
The user is interested, at best, in the power in Watt of his appliance; he assumes that he benefits from a regulated current at 230 V, plus or minus a few small, almost imperceptible variations following the constant adjustments made by the grid manager to provide a voltage that complies with the specifications, and in "infinite" quantity at least from the point of view of the individual consumer.

In the case of a photovoltaic power supply, the situation is quite different. Everyone can imagine the extent of the variations between daybreak and solar noon, but moreover, and this is much less intuitive, the production of electrical energy from a solar panel also depends on the load applied to it, which further amplifies the initial variations. This phenomenon can be found in all books dealing with photovoltaic panels.

However, a first law of electricity teaches us that the power varies according to the square of the voltage, for example if the voltage doubles, the power is multiplied by four P = (U * U) / R

Let's take an iron designed for a power P = 900 W at a voltage U = 25 V; the current consumed is therefore I = P/U = 36 Ampere, and its resistance R = U/I = 0.694 Ohm.
Let's assume that the panel now delivers a voltage of U = 35 Volt. The power becomes
P = U * U / R= (35*35)/0.694 = 1765 W. The resistor, which was designed for 900 W, is overexcited, it heats up, it's a burn out, it "snaps".

Conversely, if the voltage delivered by the panel drops to 15 Volts, the power falls to P = U * U / R = (15*15) / 0.694 = 324 Watt: my iron is no longer useful.

A second law of electricity teaches us (see for example here) that the power varies according to the square of the current, for example if the current doubles, the power is multiplied by four:
P = R * I * I .
If the initial current increases from 36 to 46 Amps, the power P increases from 900 to 1468 Watts;
If the current is reduced from 36 to 26 Ampere , P drops to 469 Watt.

This is a far cry from the 230 V regulated current of the electrical grid.

**The almost universally adopted solution** consists of interposing a battery between the photovoltaic panels and the user.
The battery plays a role in energy storage, which is what the user is primarily interested in, but just as much as storage, its primary function is also to provide a regulated and therefore usable current, without which the solar panels are useless.
But a battery also has its own high requirements. It is out of the question to connect it directly to the solar panels; another power electronic component, the charge controller, must be inserted, which plays a multiple role, among others
- adapting the current to the needs of the battery
- managing the charge of the battery
- in small installations, monitoring the discharge of the battery.

A lot of documentation is available from suppliers; solar chargers generally use an algorithm called MPPT, or PWM. On this subject, see this document in particular

Downstream of the battery, depending on the type of equipment to be powered, an inverter should also be installed to convert the battery current into 230 V AC.

Note here that all these electronic components surrounding the battery are *power electronics* devices: it is the entire electrical flow that is manipulated, transformed and adapted.

Despite a significant drop in price, these components are a burden on the budget of a photovoltaic installation. Their lifespan is much shorter than that of the panels. As for the battery, it must be recognised that
- it is expensive, especially compared to photovoltaic panels
- it is fragile ;
- its life span is limited;
- Finally, it is the most polluting element of the system.

We propose here, as part of the solution, to use ceramic PTC resistors. These resistors are subject to the same laws of electricity, but their flexibility of operation adapts well to variations in solar energy.

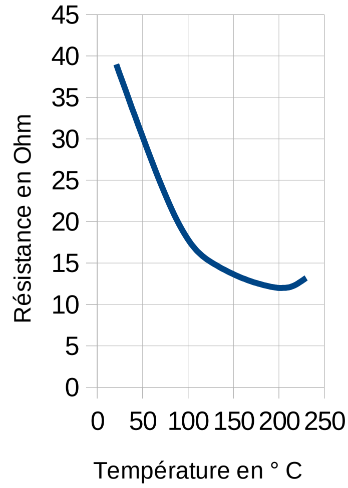
# 2 - PTC CERAMIC RESISTORS

## Description and properties.

There is a multitude of ceramic resistors. In order not to disperse, we will only talk about one kind of resistor, it will then be possible to adapt as much as needed.
Here is a 60 * 21 * 5 mm resistor consisting of
- a ceramic wafer (not visible)
- two electrodes made of very thin aluminium sheet, not visible
- two wires soldered to the electrodes; the soldering is the most fragile part: do not handle the resistors carelessly.
- an orange envelope made of very thin silicone sheet (?), ensuring electrical insulation
-an aluminium shell, ensuring the mechanical strength of the whole.

One of the main characteristics of ceramic resistors should be noted here
- Ceramic resistors are components whose resistance varies significantly according to their temperature, see for example the curve opposite. As a first approach, we can say that the resistance decreases in the proportion of 3 to 1, when the temperature increases from ambient to 200°C. The thermal power delivered by the resistor is thus multiplied by three (provided there is a sufficient power supply)
- Once the temperature of about 200°C is reached, the resistance increases very strongly, so the heat production becomes stagnant: unlike usual devices such as Nickel Chrome or others, t*here can be no burn out.*

Pour illustration:
résistance en fonction de la température




**Bibliography :**
The company TDK / EPCOS, a subsidiary of Siemens and Matsuhita, specialising in the manufacture of passive electronic components, publishes extensive documentation on PTC ceramics with a " positive temperature coefficient " and on NTC ceramics with a negative temperature coefficient.  Only PTC ceramics are of interest here. They are little known, but nevertheless omnipresent in our daily life, cf the examples provided in the introduction to the EPCOS document.

You can also consult
- the article thermistor on Wikipedia
- resistorguide.com
- Yongli Electronic Ceramics Co, Ltd Manufacturer & Supplier
- Tiancheng Co documentation
Ceramics are commonly used in electronics, sometimes presented as "resettable thermostat".

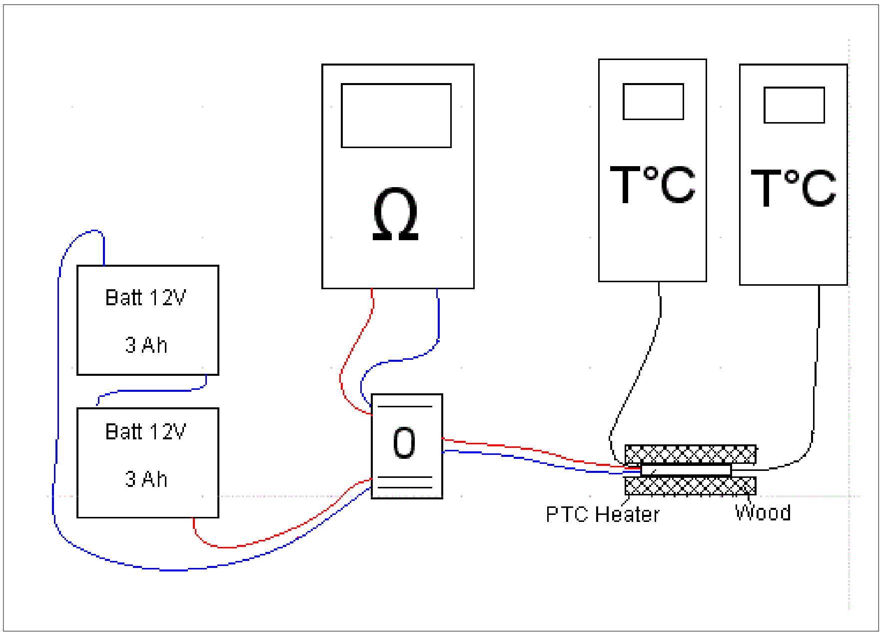
**How do you determine the characteristics of a PTC ceramic resistor?**
There doesn't seem to be a masterful answer to this question at the moment. The resistors we are interested in are available in Asia, and the suppliers are very stingy with information. They indicate a working voltage, for example: 36 Volts; and this is only a handwritten inscription on the plastic bags containing the resistors.
But "a resistor [e.g. a ceramic] does not operate at a nominal Voltage; therefore it cannot have a nominal Power. However, when the Power increases [e.g. if the Voltage increases, or if the Resistance decreases], the amount of heat increases, which can heat up dangerously and destroy the component. The manufacturer indicates a maximum power that should not be exceeded: this is the Maximum Allowable Power." (Académie Bordeaux)

**The solution adopted was**
- to set an operating voltage for the photovoltaic system, i.e. 40 volts (in open circuit), which is a legal safety voltage to avoid electrical accidents.
- to supply resistors known as "36 Volt" (but we note that resistors stamped "48 Volt" are also suitable).
- to systematically test the resistors on a test bench, at least by sampling, in order to have somewhat homogeneous batches.

In spite of all these reservations, it must be recognised that the PTC resistors in aluminium shells are the key element of the heat production device proposed here; it is only a question of using them to their optimum.

## The resistance test bench

The ceramic "PTC heater" is held between two small pieces of wood or cork. The rocker switch allows either to heat it or to measure its resistance at the same time as its temperature. 7 to 8 readings per ceramic are sufficient.



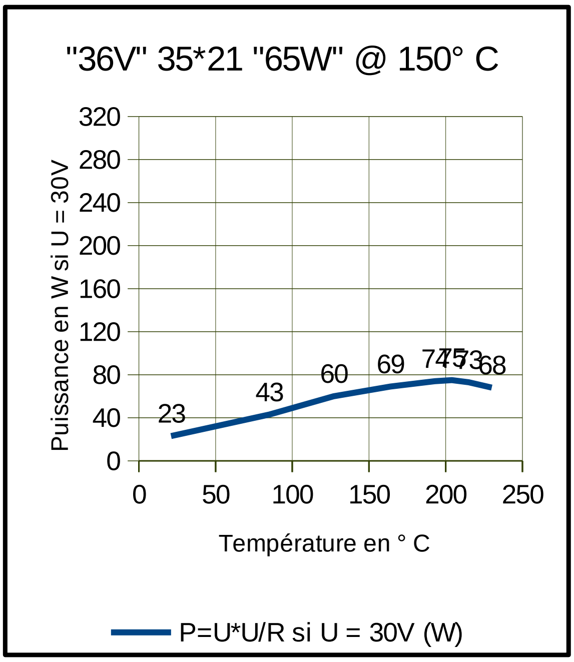
**Typical characteristics** of a 35 * 21 * 5 mm PTC resistor, stamped 36 Volts
The first two columns show the results obtained on the test bench.

The third column is the result of calculations, not measurements:
the power is calculated according to the formula P = U*U/R, for each of the power readings, and for a voltage of 30 Volt.
The voltage of 30 volts has been chosen because it is a usual operating voltage for a panel known as "40 volts open circuit", in good weather.

| "36V" 35*21 "65W" @150° | | |
|---|---|---|
| Tempé rature (° C) | Résis tance (Ω) | P=U*U/R si U = 30V (W) |
| 21 | 39 | 23 |
| 85 | 20,8 | 43 |
| 127 | 15 | 60 |
| 164 | 13 | 69 |
| 193 | 12,1 | 74 |
| 204 | 12 | 75 |
| 215 | 12,2 | 74 |
| 230 | 13,2 | 68 |

The power curve can be plotted at a voltage of 30 volts

Finally, the power at a temperature of 150°C of the resistor is noted *graphically.* After experimentation, it is considered that 150°C is an "average" temperature for the resistor to operate, although there are large variations, for example if a container of cold water is to be heated, or a container of hot water kept at 95°C. The 150° C is only a benchmark.




With these reservations in mind, the characteristics of the PTC ceramic heater can now be given:
-Dimensions 35 * 21 * 5 mm (this is the only element established with certainty)
- operating voltage 36 V, according to the supplier
- power 65 W at 150°C, according to measurements on the test bench.

But of course, the designer can use any other resistor at his convenience.

**The supply**

The sources of supply have varied over the years. A distinction can be made between Aliexpress.com , which is oriented towards the private individual, and Alibaba.com , which is more professional. Prices can vary from one to eight.
At Alibaba, this supplier has been successful. The price is around $1 each, excluding shipping.
The two manufacturers listed in the bibliography above can also be consulted.
Search under the key words "PTC heaters" or "ceramic PTC heaters".

# 3 - REGULATION

We find ourselves with a large number of variables, which are difficult to control, and yet the challenge is to get the best out of the installation.

The chosen solution consists of
- to use resistors of the type proposed above (but the designer may very well make other choices)
- to have a more than sufficient number of resistors for the maximum power of the installation.
- to control the operation of the resistors using a small microcontroller in which an algorithm of the "perturb and observe" type is implemented: with the help of two sensors, the microcontroller knows the voltage and current of the system at a given moment, and can therefore calculate the instantaneous power; then it perturbs the system, for example by implementing an additional resistor, and then observes the result obtained: if there is an improvement in the power, then the microcontroller continues in that direction; otherwise, it goes in the opposite direction The loop repeats itself indefinitely, several times a minute.

**The main elements of the control board are :**
**- the microcontroller,** in this case an Arduino Nano at 20 € in original version, (recommended) or at 8 € in clone version. A micro-controller includes a (very small) micro-processor, a (small) memory allowing to implement a program, but also and especially inputs and outputs, allowing for example to receive information via sensors (Voltage, Current), and after having processed them, to control electronic switches using PTC resistors.
**- Voltage and current sensors,** worth a few euros each.
**- electronic switches,** called MOSFETS, which now replace the old electro-magnetic relays.

**The secondary elements** of the installation concern the power supply of the above elements, which require, to function correctly, ... a regulated 5 Volt direct current supply.
Two components are required:
- a DC-DC converter 48-8 Volts/ 5 Volts . From a (permanently) variable current between 48 V and 8 V, this component produces a regulated current of 5 V - 1 to 2 Amps.
- and a battery, of the type "emergency battery for smartphones", with a capacity of 5,000 milliAmpere-Hour at 5 Volt.
The electrical consumption of the automation system is of the order of that of a smartphone.

Please note that
1. we are dealing here only with *control electronics,* which have nothing to do with the *power electronics* mentioned in the first part, particularly as regards the price and lightness of the components.
2- a major characteristic of the regulation is its safety
- in case of overfeeding for any reason, the ceramic resistors stagnate and their temperature stabilizes around 200°C.
- in case of underfeeding for any reason, the thermal insulation allows to keep the previously accumulated heat.

# 4- THE ELECTRONIC BOARD

The board proposed below is at the level of an "apprentice electronics technician supervised by an experienced electronics technician"; no attempt has been made to optimise space.

The board is presented for educational purposes only, or else for a one-off construction: its labour cost would be prohibitive. For commercial construction, a printed circuit board should be used, but this is outside the scope of this article.

Supply a 3mm thick white PVC sheet, e.g. from polydis.fr, to be cut with e.g. a fine-toothed egoin saw; width: 248mm; length: 290mm minimum; but the length cut could be made later, once all the components are installed on the sheet, the unknown is the configuration and size of the USB sockets on the Power Bank, for which you may wish to have several extra centimetres.
Draw a line around the perimeter, 10 mm from the edge: leave this perimeter strip free as much as possible, except for holes and notches for passing electrical cables; it will be possible later to install small lengths of 3 mm threaded rod, to support a transparent protection plate.

**A -List the different areas** of the board:
1 - voltage and current sensors
2 - power supply for the automatism
3 - control-command (Arduino Nano micro-controller)
4 - Mosfets remote-controlled electronic switches

**B - Arrange the components** without fixing them, or with a few small balls of adhesive paste, in order to have an overall view. The proposed diagram does not propose any precise dimensions, it would be completely useless; and in case of dissatisfaction, it is always easy to pierce the PVC again to move a component. But always install the components and cable harnesses parallel to the edges of the plate, so that the whole thing looks good at first glance: an extra hole is not a problem, but a component installed at an angle will damage the installation.
Decide on the final length of the plate, without trying to compact the assembly unnecessarily, and cut it to length.
Alternatively, if there is a lack of space, the power bank can be installed on the underside of the board.

**Item 1: Voltage and current sensors**
For the supply, see this site, Part 4 Chapter II, Section IV.
A good solution is to glue the two sensors to a small PVC plate, which can then be bolted to the general plate.

**Item 2: Power supply for the automation system**
For the supply of the DC-DC converter: see the site above, Part 4, Chapter II, Section III.

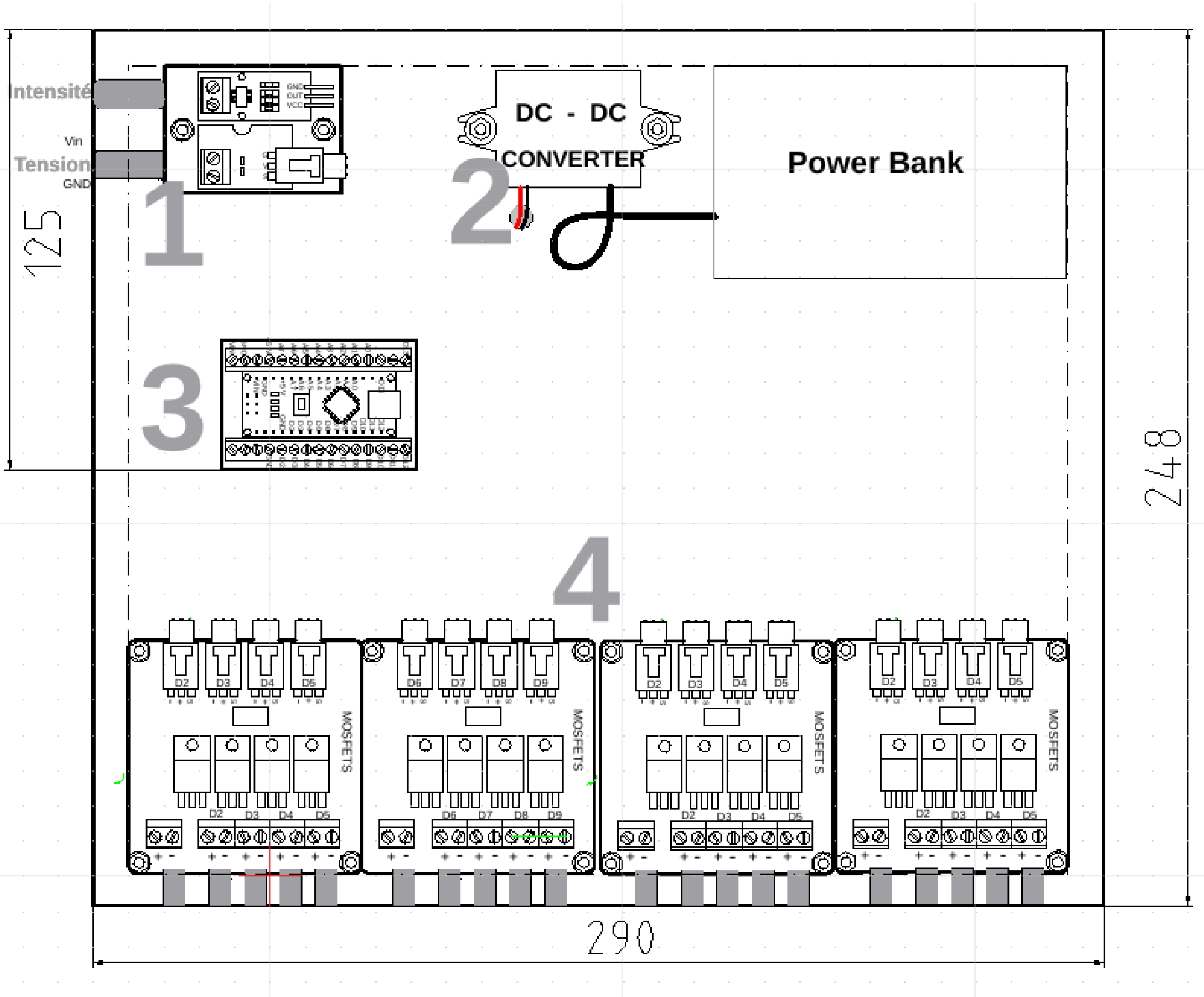
**Item 3: The microcontroller i**s mounted on a bracket that allows wiring with screws. For the moment, present only the support, taking care to orient it in the right direction
For the supply, consult the site above, Chapter II section IV

**Item 4: Mosfet remote control electronic switches** are sold in groups of four, installed on a board. For supply, see the above website, Chapter II section IV

How many Mosfets should be installed? The answer should be given well in advance of starting work, but it is not that simple:
- The number of ceramics depends on the peak power of the installation; it is advisable to oversize it somewhat.
- The more mosfets there are, the finer the regulation will be.
- A single mosfet can control several resistors.

It is up to the designer to make his choice.

## C - Drawing and making the holes and cut-outs for the cables




Make sure that there are sufficiently comfortable passageways, so that the cables do not have to be twisted.

## D - Wiring of the power circuit

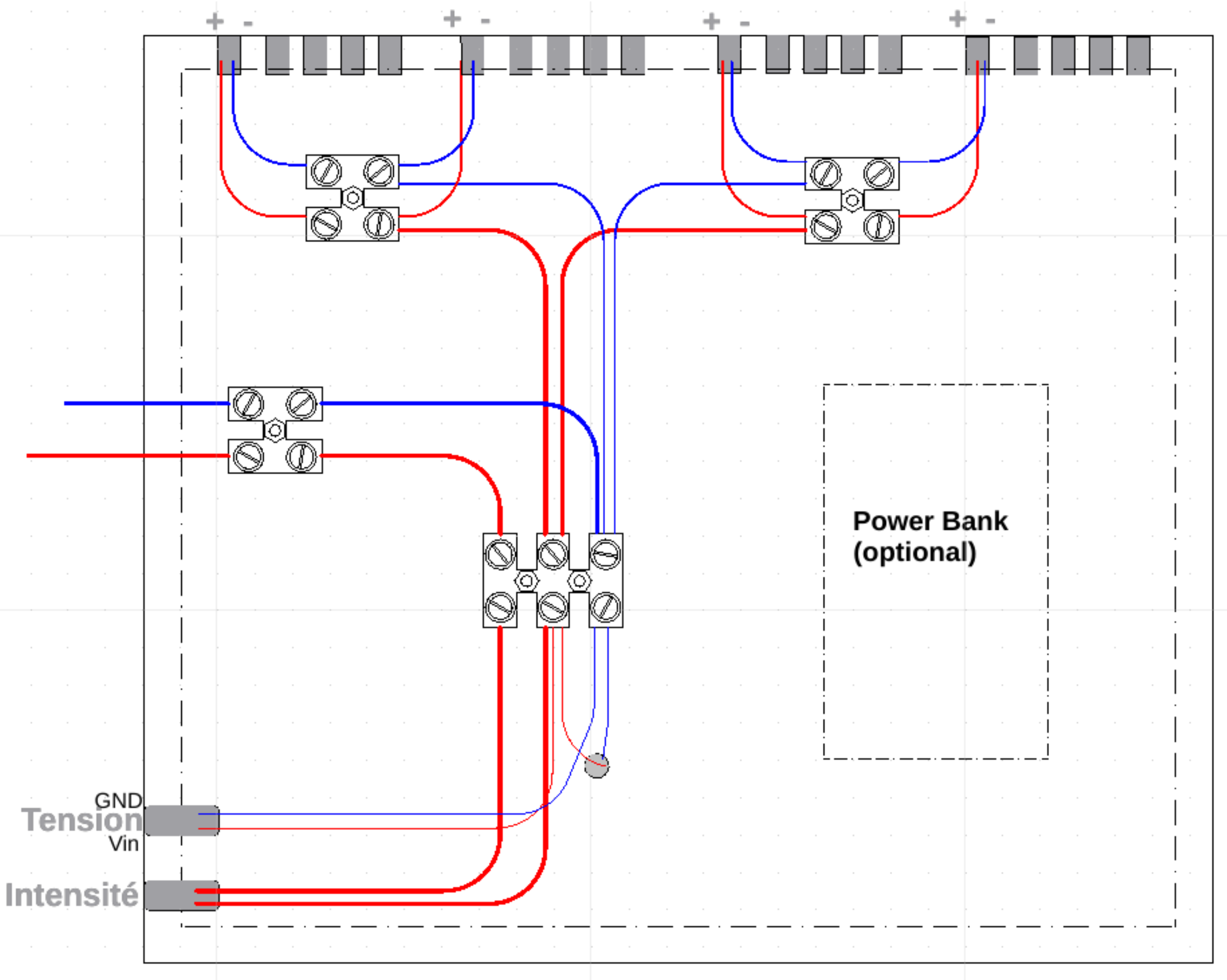
All the power circuits are installed on the underside of the board.

- The diagram below can be adapted as required
- the dominos are fixed by bolting with 2 or 3 mm diameter countersunk screws
- some of the dominoes are used to make electrical connections, but other dominoes are used simply to fix cables under the plate; other means are possible (bridges, etc.). A small dot of glue or adhesive paste under the dominoes will prevent them from turning when the screws are locked.
- For electrical connections, make sure to use the right size dominoes to ensure a good grip on the cable; in the case of flexible cables, it is essential to tin the end of the cable beforehand with a soldering iron.

Cable cross-section: the order of magnitude is 1 mm² for 6 Amperes

Connection of the current sensor: connect the cables indifferently on one or the other terminal; the transmitted signal will be either positive or negative, but the computer program will restore it if necessary in positive value.

Then turn the board over to work on the upper side



## E- Wiring the power supplies for the control circuit components

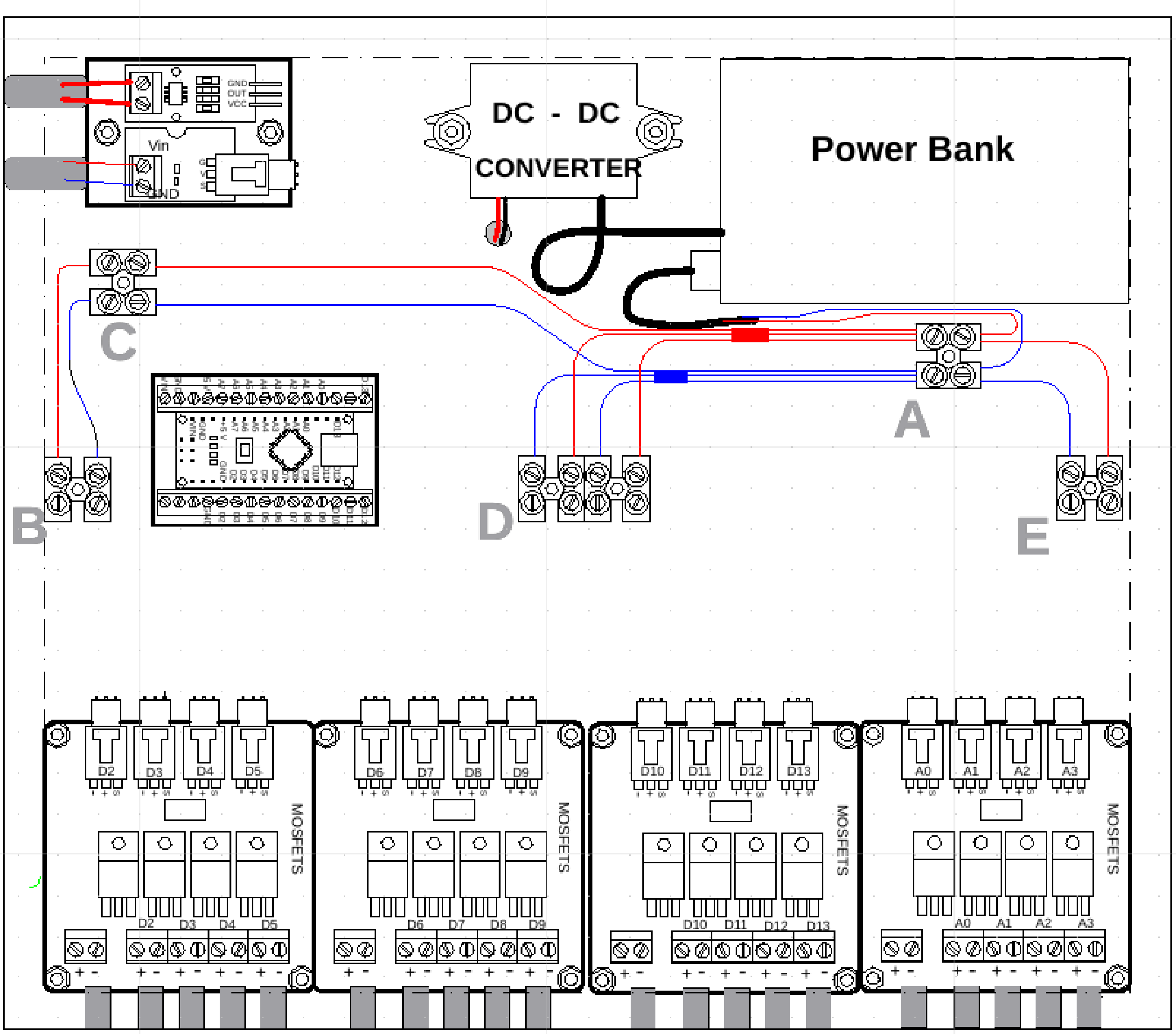
All electronic components (sensors, Mosfets, micro-controller...) need electrical energy to operate, so they must be supplied with 5 V DC by connecting them to the battery.
On components, positive terminals are designated by the term "Vin", or "Vcc", or by the "+" sign. Negative terminals are designated by the term "ground", or "gnd", or "earth", or by the "-" sign. Colour: black or blue.

**1) Connecting the power bank to the main power point "A**

On a phone USB power cord, cut a length with the usb plug corresponding to the power bank output.
USB cords have 4 wires: two of them are dedicated to power, red and black; the other two, dedicated to data transmission, are not of interest here.
Strip the two red and black wires; they can be "fattened" by soldering a small piece of cable at their end, for a good contact inside the "A" domino. Protect the whole thing with heat-shrink tubing

**2) Connect the main power point "A" to the secondary power points B,C,D,E.**

Use 28 AWG cable, i.e. a section of 0.08mm2 . See here part 5, Chap III. To group the cables correctly, you can use small sleeves cut out of heat-shrink tubing.


DC - DC
CONVERTER
Power Bank
Vin
GND
C
A
B
D
E
MOSFETS
MOSFETS
MOSFETS
MOSFETS
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
D13
A0
A1
A2
A3

### 3) Connecting the secondary power points to the electronic components of the board

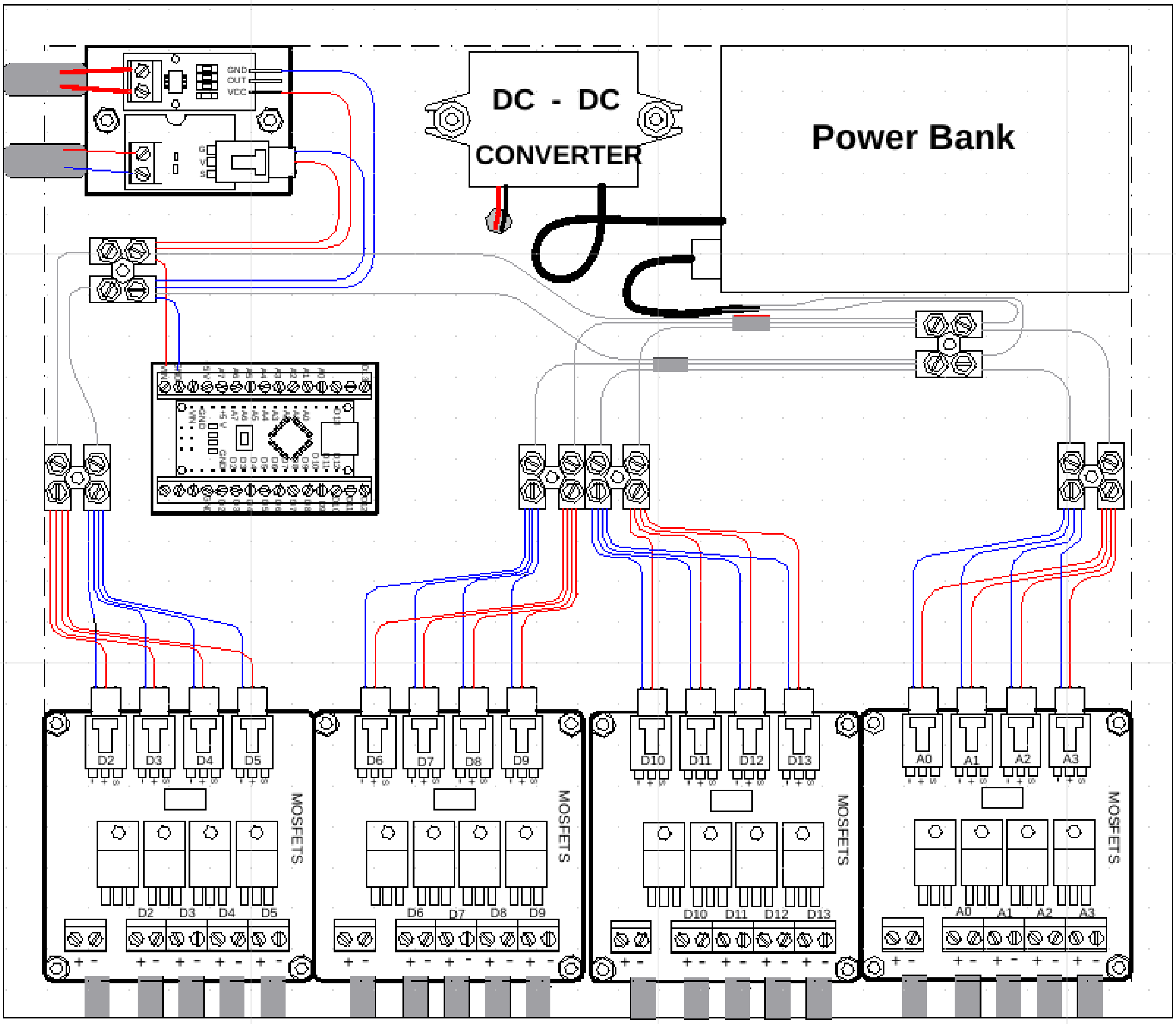
Except for the Arduino, all other components are to be connected with Dupont female connectors, also called BBJ, or others...
See Part 4, Chapter II.
For neophytes: do not waste time crimping Dupont connectors.

**A good solution** (among others): supply one or more of the female-female wires kits
For example: length 300 mm, reference ADA 1949, section 28 AWG available at semageek.com or, at Gotronic.fr, ref 12337, or 12331, or 12338 (preferably)
Cut the cables as much as necessary, the scraps can be used for other connections.
Avoid sourcing cheap cords that cannot be stripped or soldered.
Coloured sleeves cut from heat-shrink tubing can be used to make it easier to identify cables.

**The issue of black enclosures**
Electronic components are usually connected by three cables: two for the power supply, and the third for the signal.
Three "one-contact" boxes can be used for each component, but for a good mechanical connection, it is highly preferable to insert the three cables in a single "three-contact" box.
The dismantling - reassembling of the boxes is done without difficulty by delicately lifting the small black tab with the point of a knife. This is made easier if you first gently push the cable towards the inside of the case.
Supply: for example NSR-03 boxes at Gotronic.fr ref 49024

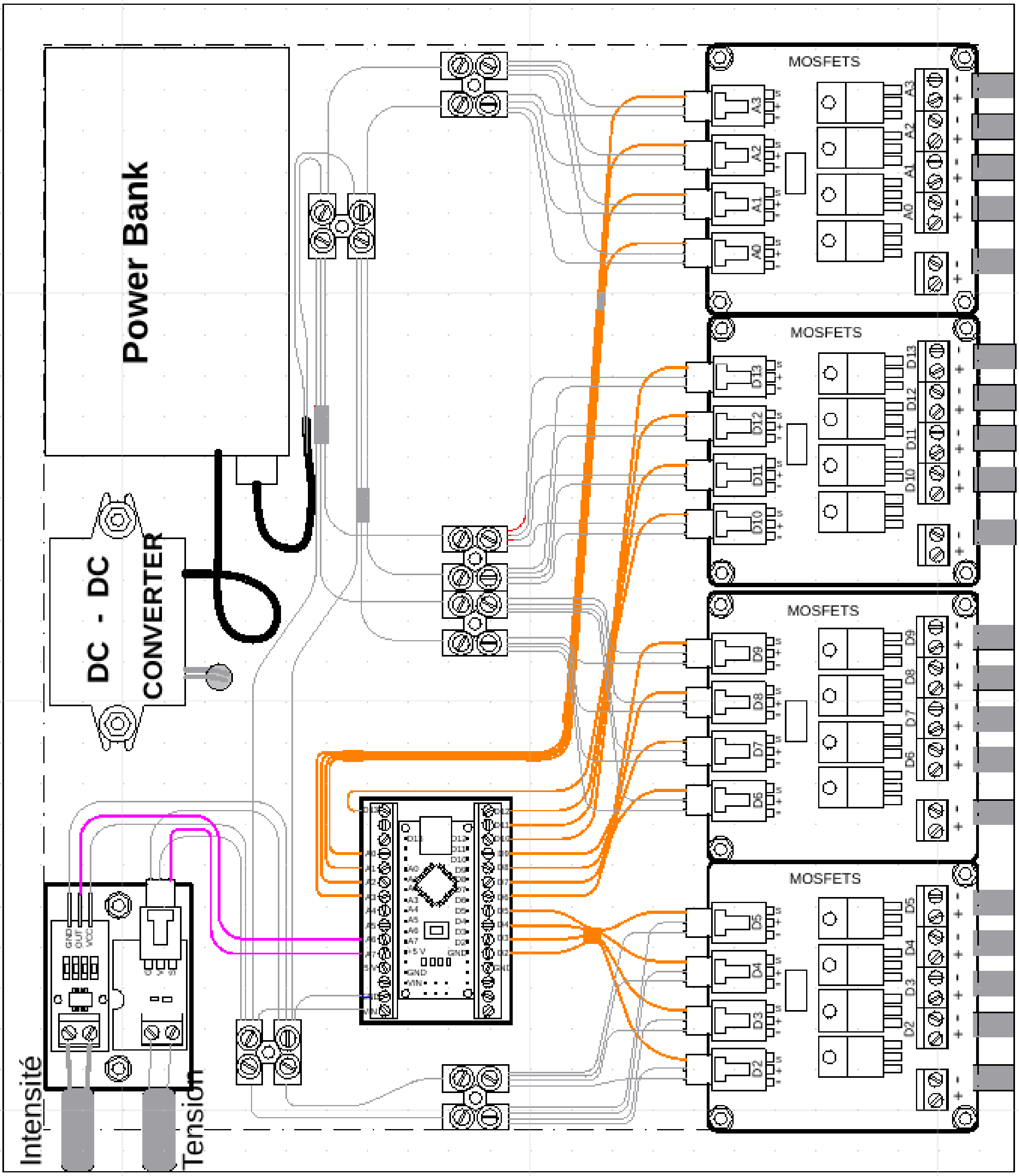
To make the work easier, stick a double decimeter on the work table so that the length of each cable can be easily measured as the work progresses.

Arduino connection: on Vin and on GND
Current sensor connection: on Vcc and on GND (the names may vary according to the models)
Voltage sensor connection: on V and G
Mosfets boards connection: on "+" and "-"; often the inscriptions are placed ...on the underside of the boards.


DC - DC
CONVERTER
Power Bank
MOSFETS
MOSFETS
MOSFETS
MOSFETS

# F- Wiring of the data and control circuit

Current sensor: from pin "out" to pin A6 of the arduino
Voltage sensor: from pin "s" (= "signal") to pin A7 of the Arduino.
The outputs of the Arduino are grouped together: D2 to D5, D6 to D9, D10 to D13, A0 to A3, to the "s" pins of the Mosfets.
Don't forget quality control !



## G - Other elements of the board

To be checked with an experienced electronics specialist:
- Is it necessary to install a diode at the head of the installation, in order to avoid confusing the + and the -?
- In the case of a high voltage, adapt the current sensor.
- Installation of a main switch?
- Installation of a wattmeter identical to that of the cooker, with a shunt ?
- Coupling of the main switch with a thermostat for the maximum temperature of the hot water.

# 5 - ABOUT THE COMPUTER PROGRAM

To take your first steps in Arduino programming, there is a lot of documentation, very educational, for example
http://arduino.education/wp-content/uploads/2018/08/Arduino_cours_sept2018.pdf
or: locoduino.org

For our immediate purpose, the reader is referred to solar cooking-photovoltaic.org Part 3, Chapter IV.

The program to be uploaded to the Arduino Nano is based on a "perturb and observe" approach: starting from a given situation, the program slightly perturbs this situation and observes the resulting evolution. If the perturbation was beneficial, then the new equilibrium is preserved, otherwise the program tries a new perturbation in the opposite direction of the previous one. The aim is to constantly optimise the use of solar energy by implementing the appropriate number of ceramic resistors

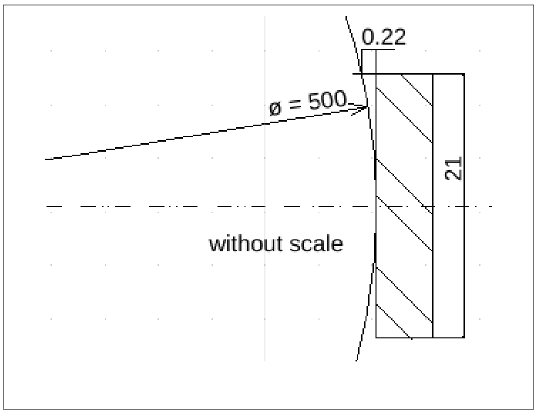
The program for the heater must be adapted to the number of ceramics used; several ceramics can be grouped together on a single Mosfet, provided that the data sheet is observed.
The program of the cooker provides for an intermediate half-level between two power levels, in order to have a better follow-up of the variations of the power supply; this is a small complication that is justified in the case of a small power installation (less than 300 W) using only half a dozen resistors, but is totally unnecessary in the case of an installation of the order of kW or more.

The program of the cooker can be downloaded here, but it must be adapted.

## 6 - ABOUT THE INDIVIDUAL WATER HEATER

We consider here the case of a prototype water heater made from an existing individual electric water heater that is stripped of its thermal insulation as much as necessary.

The ceramic resistors can be arranged in a ring around the heater, firstly strapped with a bungee cord or similar, and then in a more permanent manner.




To adapt the heater to the curvature of the tank, a 0.5 mm lead sheet or similar can be used (available on the internet).
Form a hardwood template with a file, and grip the template and the lead sheet in a vice to deform it to a depth of 0.22 mm

At what level of the heater should the resistor ring be installed? At the top or at the bottom? The question is open to debate, depending on various parameters, but it is beyond our immediate scope. A good answer is probably: one at each level; with a slight complication, the automatic system can then switch from one to the other to optimise the whole.

Another possible solution is to install a thermo-siphon U-tube under a water heater.

This hot water device then reaches an incompressible degree of simplicity, at least in the current state of technology.

Skeptics or disbelievers can try a "proof of concept" with a 60-litre or 200-litre drum, to be connected to solar panels kindly made available for a few days (without having to move them of course). It's almost playful.
Playful? See this short video: the heat transfers are not optimised, nor is the electrical installation, but we can only applaud what seems to be a first.

## 7 - ABOUT SWIMMING POOL HEATING

On a technical level, the case of a swimming pool is simpler than that of a water heater, because of the permanent circulation of the water. The ceramic resistors are to be installed on a small length of metal tube (round or square?) inserted in the circuit. When calculating the number of resistors, take into account the low operating temperature level of the ceramics (compared to that of a boiling cooking vessel), and therefore their relatively low thermal power, see the graph and table in § 2 of the full version of this document. The microcontroller will then optimise the operation of the system at all times, so as to make the most of every ray of sunlight.

SWIMMING POOL HEATING and SOLAR COOKING: what is the connection?

The small team of solar-photovoltaic-cooking.org informally gathers (or more precisely: has gathered) a few retired people from the industry working without any commercial or other aim on an electro-solar cooking device mainly intended for emerging or developing countries, as a substitute for fossil fuels or firewood in short supply.

It is clear that the process is not taking off quickly, for a number of reasons that are beyond the scope of this paper.

By proposing the use of ceramic heating elements for the production of domestic hot water and the heating of swimming pools, it is possible that the dissemination of ceramic heating technology will be faster, taking into account the economic stakes and the energy context. This would in turn favour the dissemination of the process for solar cooking.

In this case, " What’s good for swimming pools is good for cooking".

## 8 - OTHER APPLICATIONS

The storage of domestic hot water favours the intelligent use of solar energy, to be shared between self-consumption and injection into the grid at optimal times. The use of ceramic resistors for hot water production contributes to reducing the cost of the battery park, thus favouring self-consumption.

The use of ceramic heaters is perfectly suited to inter-seasonal heat storage, see the article of the same name on Wikipedia

But all these subjects are beyond our immediate scope.

## 9 - SMALL-SCALE FOOD CANNING AND ESSENTIAL OIL PRODUCTION: SOME PRELIMINARY THOUGHTS.

These are some personal thoughts of the writer of these lines.
It would be a question of an installation of the order of 6 to 9 kW

### A) Solar thermal energy.

It is technically possible to supply a 6 to 9 kW system with energy by thermal means: the writer of these lines has produced steam at 6 bars/150°, cooked food, carried out medical sterilisation and produced ice using an adsorption system.

But the thermal route is technologically complicated, and a small installation has as many complications as a large one: there is no scale effect in the number of complications, and in a small installation, the management of complications, called "impedimenta" by the Romans, and more bluntly baptized by a famous general of the french Empire, becomes prohibitive: feeding the boiler, adapting to variations in sunlight, general surveillance, require a full-time person with no other concerns. It would be necessary to specifically train a person qualified in a technological field that belongs to the past and for which there is no longer any culture. This is completely unacceptable for a small 6-9 kW installation.

There is a scale effect in terms of heat losses, which are proportionally greater as the size of the installation decreases. An efficiency of 40% in relation to the solar flux would be a very good figure.

The installation would have no other use than to produce steam for sterilisation: over how many working hours per year would it be possible to amortise the installation financially?

Finally, it would be prudent to double the solar installation with a conventional steam production backup, to compensate for the vagaries of the weather.

As for the price of the installation, it would be a prototype price.

**B) Solar photovoltaic energy**

Whatever the power of the field of mirrors: 3, 6 or 50 kW, it is necessary to amortize it financially in the best conditions, i.e. to make it work permanently, including outside sterilization hours, in self-consumption (among other things, to produce hot water, of which agro-food installations are large consumers), and/or by optimizing the sale of current on the grid.

In the case of a "green" sterilisation installation, it would be prudent to distinguish, if only conceptually, between energy production (the solar panel field) and energy consumption (the sterilisation installation). And given the amounts to be invested, the different amortisation periods, the different operating conditions, energy production and consumption could be two different legal and economic entities, even financed by different sources, while being closely linked to each other by a form of "preferential contract".

In the case of a food sterilisation plant, there is no question of using the ceramic resistors, due to the requirements of the process control system, and the need to be able to resort to the grid in the event of a temporary shortage of solar panels. Photovoltaic electricity would then be used "as usual".

In the case of a plant for the production of essential oils, the conditions are different; with the help of a skilled professional and depending on the configuration of the boiler, it should be possible to make it a "dual-energy" plant capable of operating simultaneously or separately on the one hand with the solar field, and on the other hand with grid electricity or an oil burner.

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Written by Jean Boubour, member of photovoltaic-solar-cooking.org, which informally gathers some retired people from the industry in Brest (France) working without any commercial or other aim on a device of electro-solar cooking, and incidentally of production of hot water.

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