Botijo - a fridge that works with water and wind

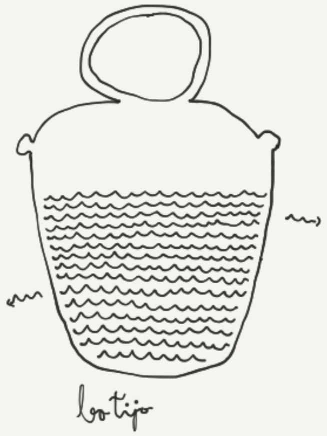
A botijo is a porous clay vessel used to cool water. In rural Spain it has been used for centuries. It works easily:

- The water inside soaks the ceramic container.
- The porous skin in contact with the outside air gradually evaporates the water.
- The water to become gas from liquid requires energy, thus it “steals” heat from the container and the water cools down (530 kCal per gram of water evaporated).

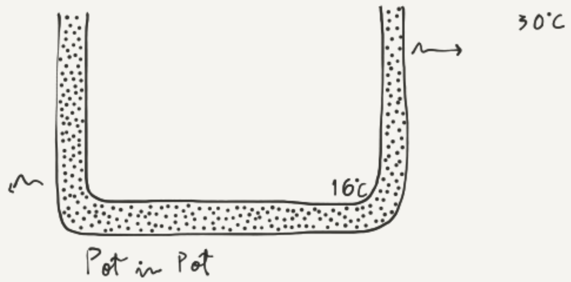
from botijo to cooler

In different parts of the world, the botijo principle is applied to extend food preservation. These responses are given mainly in contexts where energy is scarce or insecure (with frequent network outages). Evolution of the proposals:

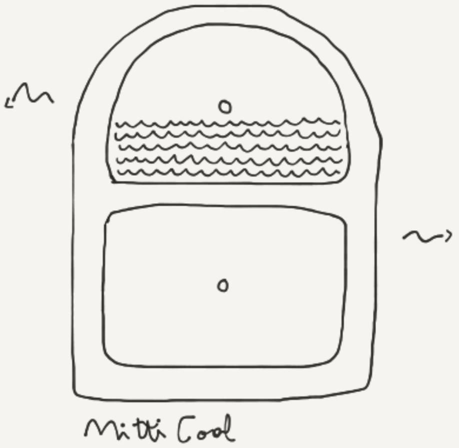
1. Botijo – Spain
    - Achievement: cooling water.
    - Cost: 6€
    - Consumption: the water itself stored for drinking.



2. Pot in Pot – Mohammed Bah Abba, Nigeria
    - Achievement: clay cooler for food preservation (tomatoes up to 20 days; eggplant up to 27 days).
    - Cost: 2€
    - Consumption: incorporates a sand layer between both pots for better distribution of the water. It requires a constant filling of water (every 2 hours approx). Food is placed in the inner pot.

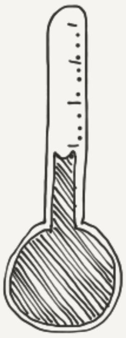


3. Mitticool – Mansukhbhai Prajapati, India
    - Achievement: clay cooler for food preservation (vegetables up to 7 days; milk up to 5 days). The internal temperature drops 10 / 15ºC vs the ambient temperature.
    - Cost: 90€
    - Consumption: water tank included for 3 days of autonomy.



the challenge

These solutions have a significant impact but are not able to guarantee proper or long-lasting preservation of meat and milk. All these answers found the same problem, getting lower than 5ºC.



Reaching 4ºC is a key milestone to avoid food spoilage. Lactic acid bacteria that cause spoilage multiply rapidly in food between 5ºC and 65ºC. Therefore, this type of solution is considered a refrigerator and not a refrigerator.

from cooler to fridge

To achieve the 4ºC goal regardless of the given temperature and humidity, external conditions must be changed, even though virtually.

This can be done by boosting the drying of the outer surface with an air flow. Just like a bathroom dryer does with our hands or the wind with our lips. The chimney effect creates a current of air that speeds the water evaporation rate and therefore the fridge cooling.

Process:

1. Evaporative cooling fridge with porous clay pot.
2. Filling of the inner layer with wet sand. It has a glazed inner container that prevents the liquid permeation and gives thermal inertia to the system.
3. Collection of rainwater or air condensation (day/night cycle).
4. The process is boosted by the chimney effect to increase the thermal difference down to 4ºC inside.

This proposal was exposed in the Beijing Design Week 2016 in the Dashilar Open Source Regeneration Hub space arranged by Laboratory for Creative Design (LCD).

testing the proposal

In January 2019 I tested the air flow effect in a Pot in Pot.

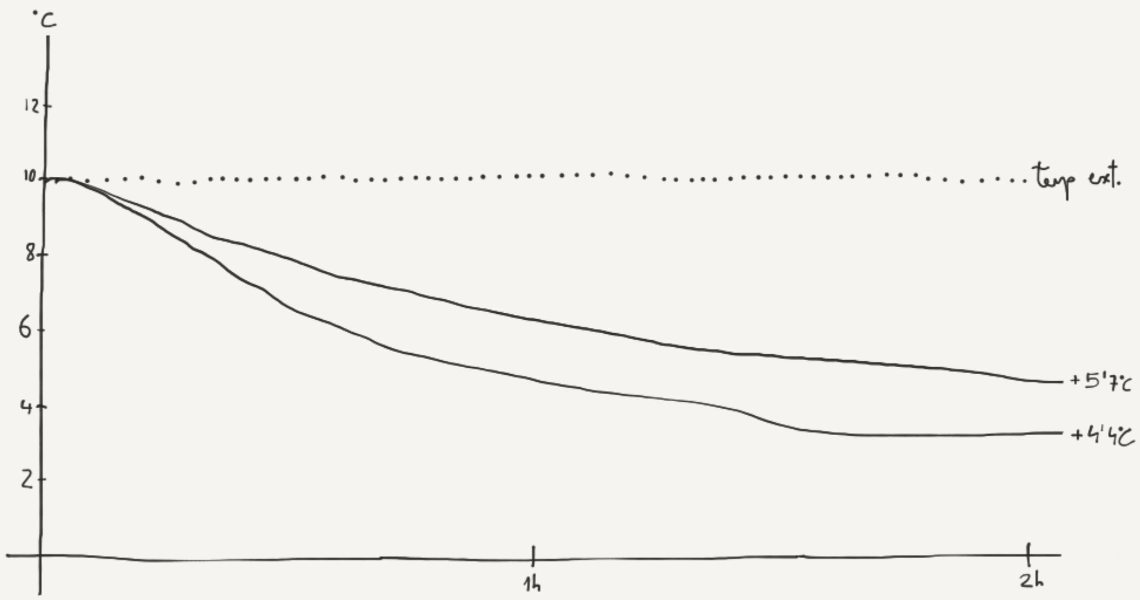
Hypothesis: the action of air flow promotes the evaporation of water and therefore the cooling of the system.

Test: results comparison of three hygrothermal meters (temperature and relative humidity).
- The first one in the outdoor environment: a closed room to prevent uncontrolled air flows.
- The second one inside a pseudo Pot in Pot (control).
- The third one inside another pseudo Pot in Pot with air flow. The air flow is generated by a fan and absorbed by a curtain to prevent the air flow impacting the control pot.

Both internal sand layers were filled with water every half hour. During the experiment it was evident that the effect was being achieved as the fan's Pot in Pot had much drier sand.

Result: the following graph shows the results obtained.

- Room meter: dotted line.
- Control meter: dropped from 10ºC to 5.7ºC in 2 hours.
- Fan meter: dropped from 10ºC to 4.4ºC in 2 hours.



Limitations:

1. As the test was done in a closed room, the ambient relative humidity rose to 89%, close to saturation. This reduces the evaporative capacity of the Pot in Pot due to the wet bulb effect.

2. The room started from an already low temperature (10ºC). In a room at habitable temperature (between 18ºC and 26ºC) the system will take longer to reach 4ºC. In order to avoid that the thermal gains from the external environment (which increase with a greater temperature variation inside / outside) do not exceed the cold generated by the forced evaporation, it will be necessary to find the proper conduction / insulation balance of the intermediate layer.

3. The wet bulb limit is removed by the air flow as the accumulated vapor around the ceramic surface is evacuated.

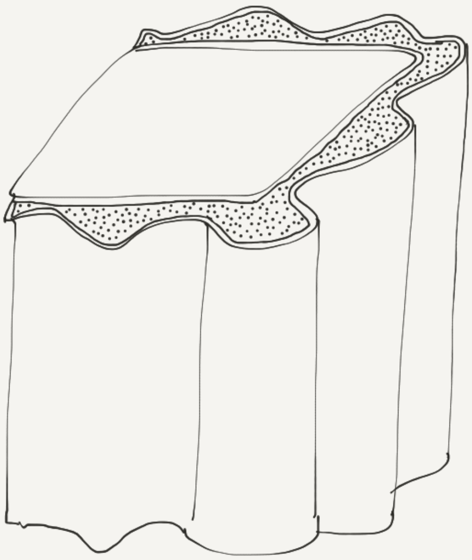
future lines

It is shown how joining a botijo with a chimney can achieve a passive fridge that only requires water to run.

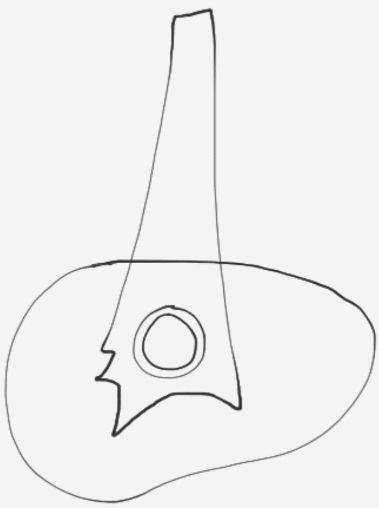
To make a fridge truly applicable to our day to day, this concept must evolve. Some possible lines of work are listed below:

- Separate the envelope of the container from the evaporative surface. Thus we avoid the double flow of energy transmission: the heat that comes out when the water evaporates (cooling); and the heat that wants to go inside due to a higher temperature outside (heating). By replacing the evaporative surface we can recirculate the cold air achieved and concentrate it in the fridge, which is completely isolated.

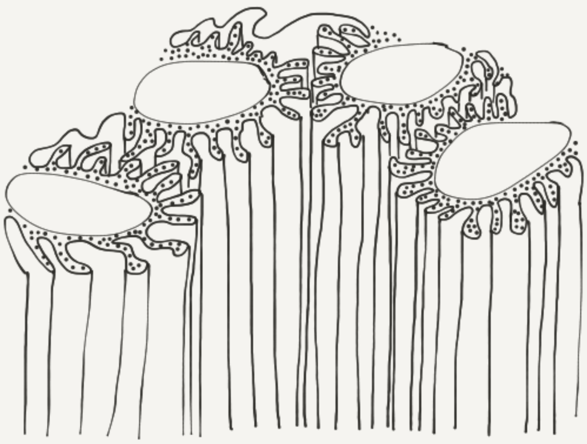
- Increase the surface to achieve greater evaporation and therefore greater cooling.



- Take advantage of the thermal inertia of the soil where the building is located. Place the fridge half buried. The temperature at a certain depth is constant throughout the year and is equal to the place average annual surface temperature. This can be measured inside the caves. In summer a lower thermal variation is achieved. In winter, cold air can be introduced from outside to have an even lower temperature.



- Take advantage of the facilities columns (which are the vertical holes that exist in the buildings from the ground floor to the roof) to use them to get air flows. It can be compatible with the facilities by a good design.



the botijo equations

This fridge system is defined by three variables:

- X outdoor temperature: set by the weather.
- Y relative humidity: set by the weather.
- Z air flow: depends on the chimney. By modifying the air flow, the system adapts to different weather conditions to ensure a constant 4ºC inside.

In 1995, Gabriel Pinto and Jose Ignacio Zubizarreta of the Polytechnic University of Madrid developed a mathematical model for a spherical botijo. The process is described by two differential equations:

$$-(dV/dt) = K' \cdot a \cdot (Hs-H)$$

$$V \cdot Cp \cdot (dT/dt) = hc \cdot a \cdot (Tg-Ts) + f \cdot \text{€} \cdot o \cdot (4 \cdot pi \cdot r^2 - s) \cdot [(273+Tg)^4 - (273+Ts)^4] - U \cdot a \cdot (T-Ts) - lambda(w) \cdot (dV/dt)$$

Where:

- V = water volume
- t = time
- K’ = mass transfer coefficient for water
- a = external surface area of water
- Hs = saturation humidity
- H = air humidity
- Cp = heat capacity of water
- T = water temperature
- hc = convection coefficient
- Tg = air temperature
- Ts = water surface temperature
- $f \cdot \text{€} \cdot o$ = heat radiation coefficient
- $4 \cdot pi \cdot r^2$ = total surface area of the botijo

- s = area of water in contact with air
- U = heat transfer coefficient of water
- lambda(w) = vaporization heat of water

In 2017, Carla Ortiz Dominguez applied the same equations to the Pot in Pot and carried out more experimental tests.

references

Pot in Pot – Muhammed Bah Abba

Mitticool – Mansukhbhai Prajapati

UPM – J.I. Zubizarreta, G. Pinto

UPM – C. Ortiz

Beijing Design Week

Miguel Acebron