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# PASSIVE SOLAR COLLECTOR FOR INDIRECT SMALL-SCALE DRYER

Link

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## Contents


- INTRODUCTION
- DESIGN AND IMPLEMENTATION
- PRELIMINARY TESTING CAMPAIGN
- THEORY OF THE CAN TES COLLECTOR
- TESTING CAMPAIGN
- CONCLUSIONS

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- **INTRODUCTION**
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# INTRODUCTION

## Food solar drying

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- According to FAO, 30% of agricultural crops are lost worldwide.
  Reasons:
    - Cropping season is short.
    - Lack of modern transport and/or cold storage.
    - Lack of knowledge
- In-situ drying is a good preserving method (less weight, not energy consuming …) but,
    - Needs much heat to evaporate water → same problems as cooking.
    - The product can be smoked, reducing quality and potentially toxic
- Solar drying is an option improving open-air drying

# INTRODUCTION

## Food solar drying

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Advantages of solar drying over open air drying →

- Less space required.
- Faster drying.
- Protects load against: rain, dust and insects as it is enclosed.

Principles of operation and types or dryers:

- Direct: The sun heats the load directly
- Indirect:
  - Heats air to increase its moisture capacity (SAHC).
  - This air heats and dries the load.
  - Air is discarded.
  -

# INTRODUCTION
## Conventional food solar drying

- Process of indirect solar drying during the day
  - Air is heated in a SAHC reducing its relative moisture.
  - Hot air contacts the food heating it < 70 ℃.
  - Superficial humidity evaporates cooling the food.
  - Moisture is evacuated by the flowing air (convection).
  - Humidity migrates from the inside to the food surface.
  - The food reduces in weight and size.

- During off-sun hours.
  - ☹ Temperature decreases and air moisture increases.
  - ☹ Mold can grow.
  - ☹ Condensation is possible on the dryer surfaces.
  - ☺ Internal homogenization of humidity contents.

# INTRODUCTION

## Objectives

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- Develop a passive Solar Air Heater Collector (SAHC) of the cabinet type
    - Does not need electricity, even no PV as it presents high cost, breakdown and thieving risk and difficult repairing.
    - Incorporating Thermal Energy Storage (TES) to:
        - Limit day maximum temperature
        - Continue drying during the night and avoid spoilage.
    - Low cost.
    - Components transportable to remote locations.
    - Local construction with common tools.
- Characterize its performances.

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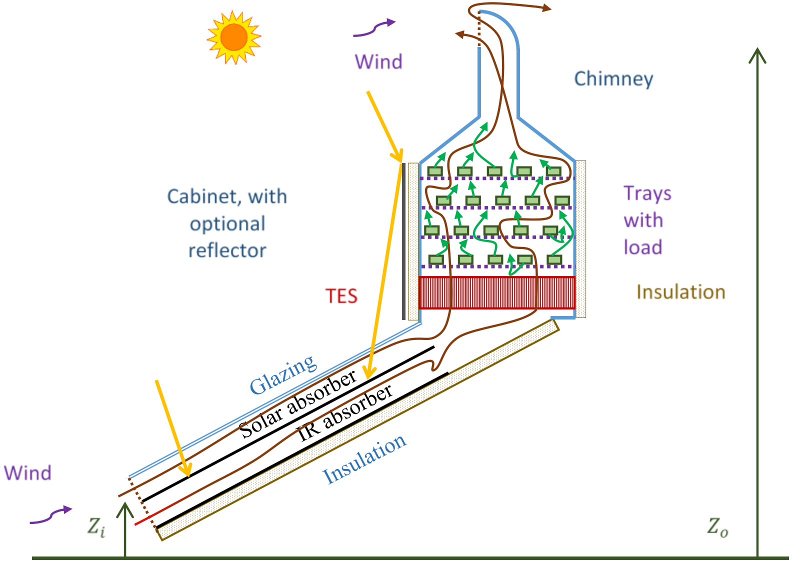
# DESIGN AND IMPLEMENTATION

## Main issues. No TES dryer

Conventional cabinet type passive solar dryer:

- Flat plate solar collector.
- Tilting allows natural draft as $\rho_o < \rho_i$.
- Chimney can increase natural draft $Z_o > Z_i$.
- TES would be highly convenient.
- Parallel air flow with two absorbers:
  - Higher efficiency
  - Avoids insulation melting




Passive solar dryer with downstream TES.
Link Lecuona, A. Solar convective dryers for post-collection processing.

# DESIGN AND IMPLEMENTATION



## Main issues

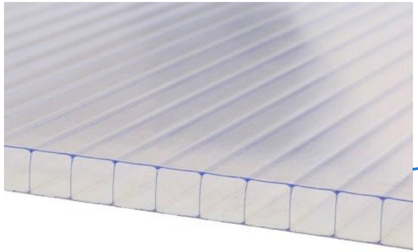
The low temperatures for drying calls for Thermal Energy Storage (TES):

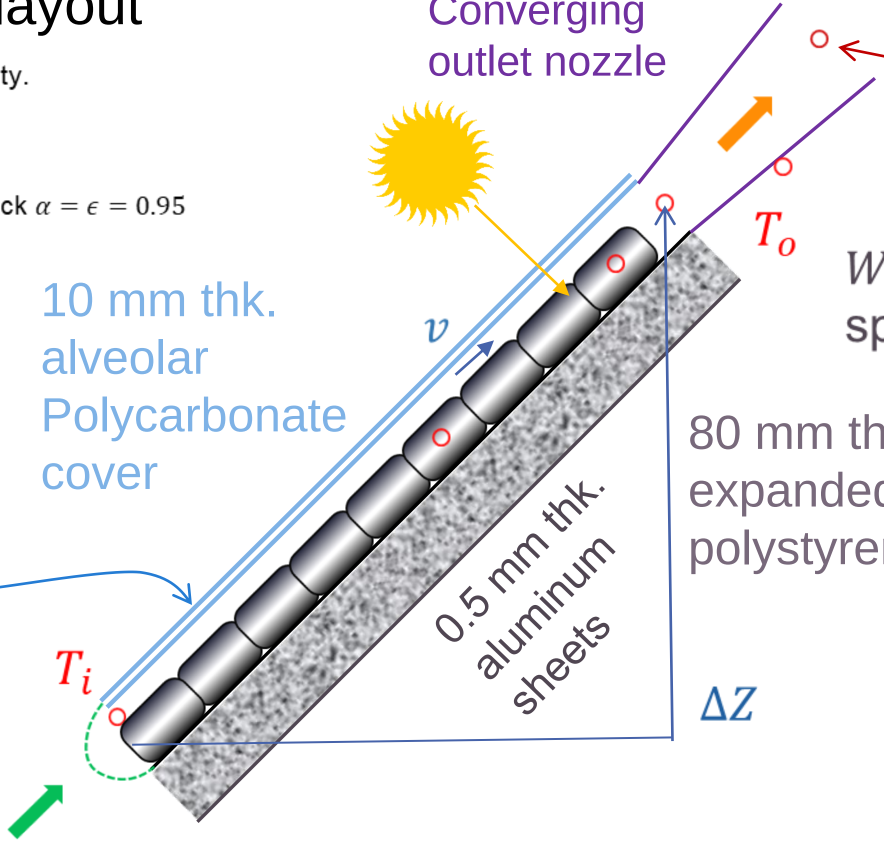
- Low cost TES is provided by water.
- Water storage is a problem because of: corrosion, vapor pressure and cost of the tank.
- Solution: Soft drinks cans **filled with non-caloric tea** (99.9% water, non-carbonated):
    - Worldwide available.
    - Low cost 20 c€/ea. in Spain (cold tea).
    - Easily transportable (valid for emergencies).
    - Durable (in-house tested up to 80 ºC).
    - Can absorb the sun rays when painted black.
    - High surface to volume ratio.

# DESIGN AND IMPLEMENTATION

## Prototype layout

- 33 cl capacity.
- 66 mmØ.
- 116 mm length.
- 14 g aluminum
- Painted dull black $\alpha = \epsilon = 0.95$






Hot wire anemometer+ temperature

$W$ = 8 cm wide air space without cans

80 mm thk. expanded polystyrene

° Type K thermocouples monitor several input, output and half-path air temperature + can temperatures

Anti-insects wire screen, inlet

# DESIGN AND IMPLEMENTATION

## Some figures

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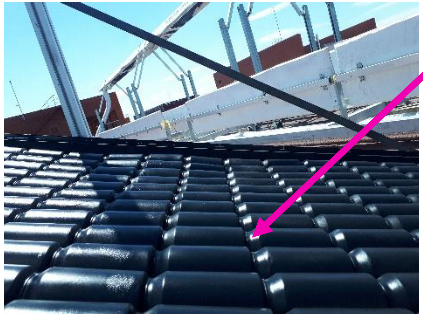


- $W = 1\ \mathrm{m};\ L = 2\ \mathrm{m} \rightarrow$ 2 $m^2$ aperture surface.
- 14×17 = 238 cans→50 € →78 liter →312 kJ/K.
- With 30 K overheat they can evaporate (dry) 4 kg of water overnight.
- Central depression was caused by back insulation melting when using empty cans in a preliminary study.
- Surface in contact with air: 2.9 $m^2$ upper side, and 2.9 $m^2$ lower side.
- Turbulence enhancement at the can union points
- Constructed in aluminum, it can be constructed in hardboard or plywood on site.
- Testing in UC3M Campus, Leganés, Madrid, Spain.

# DESIGN AND IMPLEMENTATION

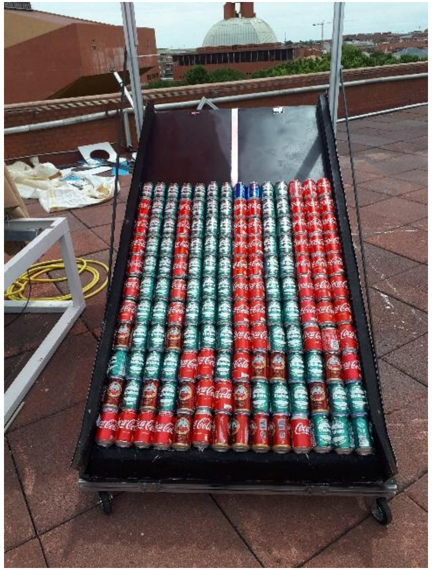
## Instrumentation

- TSI and PCE handheld hot wire anemometers in the center of a 120×120 mm outlet collection section:
  - Converging nozzle to reduce boundary layer thickness.
  - It introduced some heat losses.
- 8 channel PICOLOG/TC-08 A/D with USB to computer.
- Several handheld thermocouple displays.
- MACSOLAR handheld piranometer.

- 40 deg. fixed tilting angle + azimuth sun tracking.
- Located at UC3M Campus in Leganés, South of Madrid, Spain.
- The small temperature differences require a careful thermocouple calibration

# DESIGN AND IMPLEMENTATION

## Previous experimental studies



Empty cans tests to determine $h_a$

Low cost pre-heating for cloudy days

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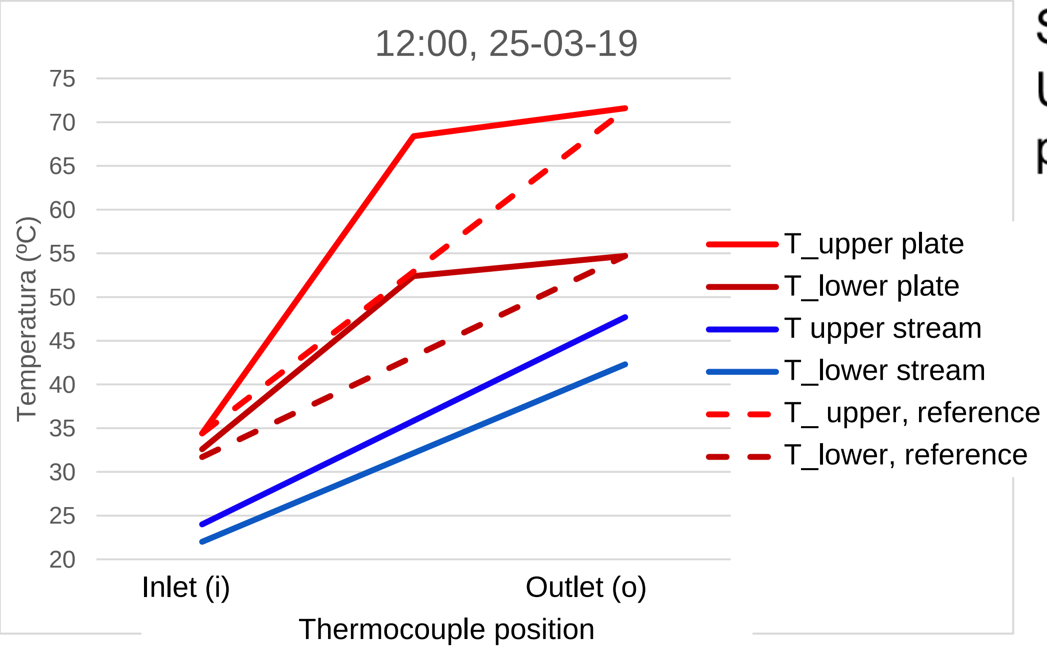
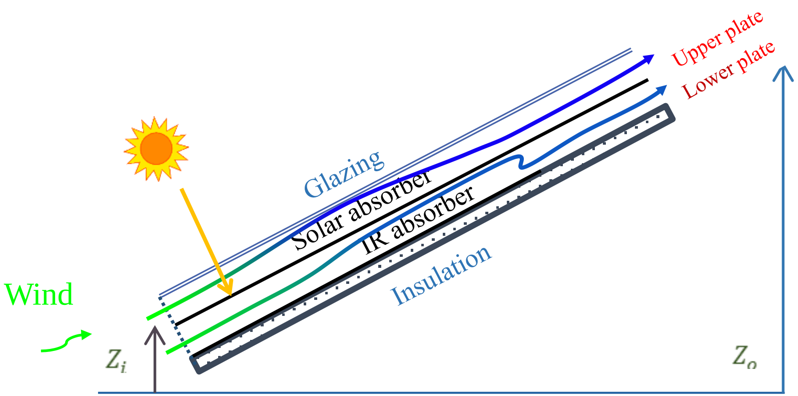
# PRELIMINARY TESTING CAMPAIGN

## Parallel plates. No TES. Axial temperature profile




Separation $W_{upper} = W_{lower} = 4$ cm

Upper plate more active than lower plate → optimize separation




- Inhomogeneity in outlet stream flows were detected, also instabilities

# PRELIMINARY TESTING CAMPAIGN

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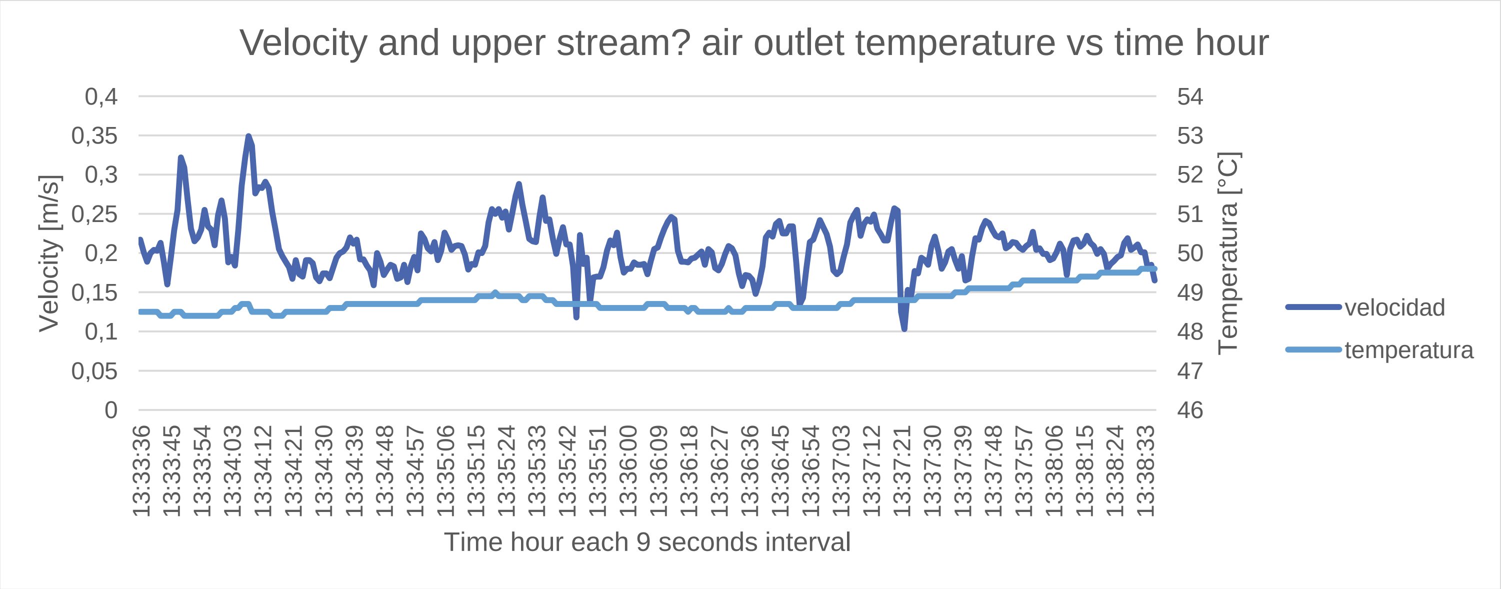
## Parallel plates. No TES.

## Instantaneous measurements of outlet air temperature and velocity




- Low velocity and high wind sensitivity.

# PRELIMINARY TESTING CAMPAIGN

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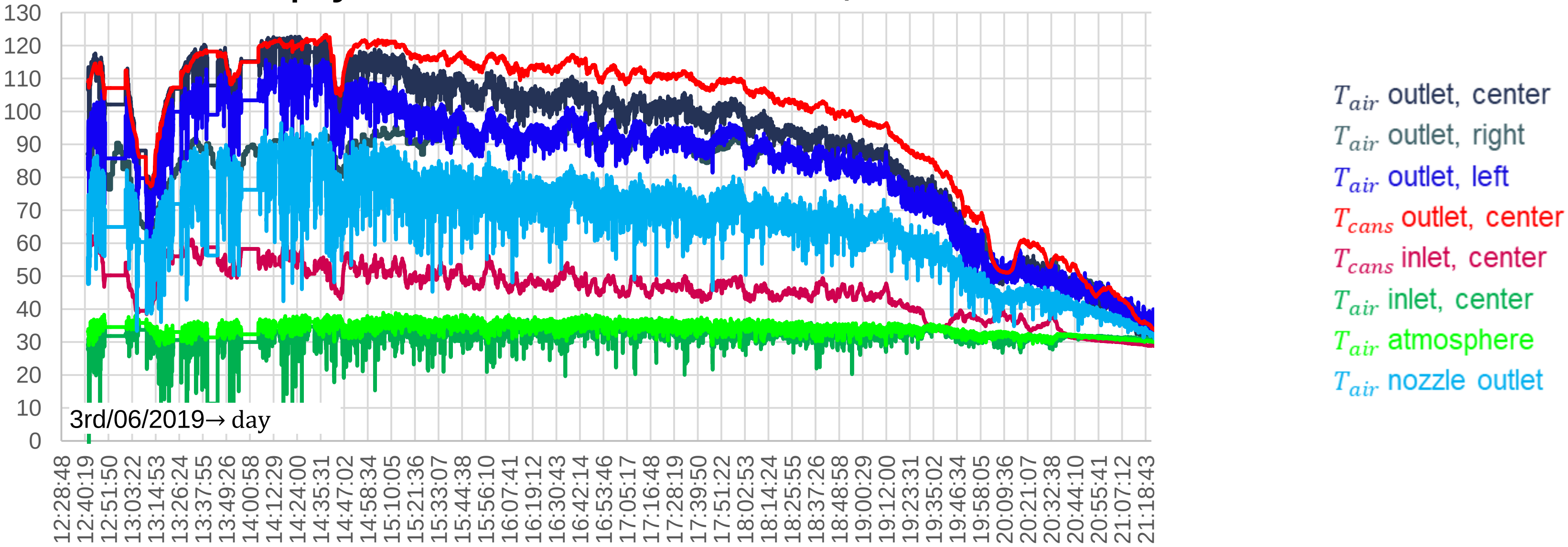
## No TES, empty cans. Instantaneous temperature measurements




- Cold gusts perturbate the measurements.
- Temperature differences between the air temperatures at right, center, and left plate outlets and nozzle exit (possible heat losses or external air contamination).
- Cans temperature differences between plate inlet and outlet.
- Fast cooling after sunset, at 21 h drying stops.

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# DESIGN AND IMPLEMENTATION
## Natural draft velocity & heat transfer

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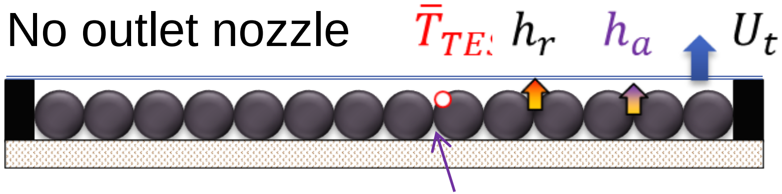
No outlet nozzle




Lower flow neglected

$$T_{atm} = 30\ °\mathrm{C};\ T_{ao} = 65\ °\mathrm{C}$$

$$\bar{T}_{TES} = \frac{T_{cans,i}+T_{cans,o}}{2} = 85\ °\mathrm{C}$$

$$\tilde{\rho} = \frac{\rho_i+\rho_o}{2} = 1.046\,\frac{\mathrm{kg}}{\mathrm{m}^3};\ b = \frac{\tilde{\rho}}{\rho_{atm}} = 0.885$$

$$v_g = \sqrt{g\Delta Z} = 4.1\ \mathrm{m/s}$$

$$D_h = 3.5\ \mathrm{cm};\ K = \frac{\Delta p_t}{(\rho v^2)/2} = 30$$

$$v = v_g\left(\frac{2(1-b)}{\left(2-\frac{1}{b}\right)+bK}\right)^{\frac{1}{2}} = 0.37\,\frac{\mathrm{m}}{\mathrm{s}}$$

$$Re_{D_h} = 502;\ Ra_{D_h} = 9.2\times10^4$$

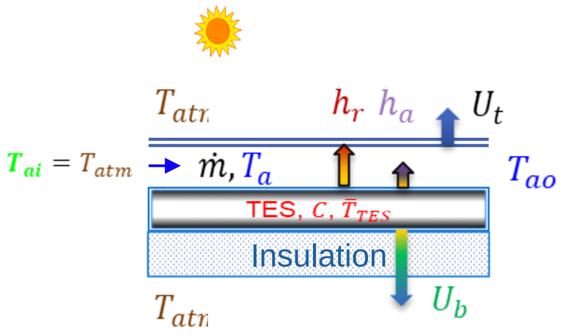
$$Ra_{D_h}\frac{D_h}{L} = 1.6\times10^3 \rightarrow \text{Forced laminar regime, rough absorber: } h_{a+r} \gtrsim \underbrace{10\,\frac{\mathrm{W}}{\mathrm{m}^2\,\mathrm{K}}}_{\text{Fron.}}$$

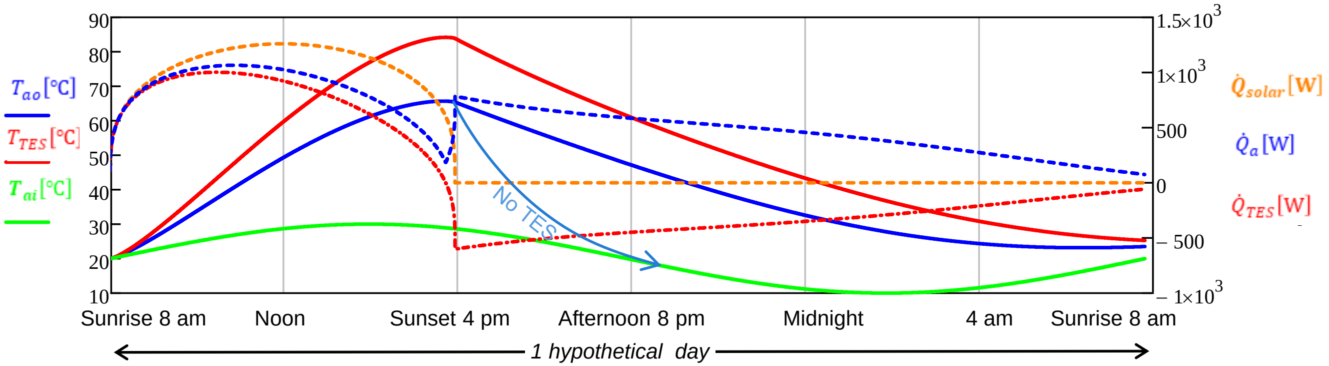
# THEORY OF THE CAN TES COLLECTOR

Simplified approach, homogeneous

$$\frac{\overbrace{\dot m c_p}^{\text{cnt.}}\, dT_a}{W\,dx} = \overbrace{h_a}^{\text{cnt.}}\left(\overbrace{\overbrace{\bar T_{TES}}^{\text{cnt.}}}^{t_{res}\ll t_{G_T}} - T_a\right) + \overbrace{U_t}^{\text{cnt.}}\left(\overbrace{T_{atm}}^{\text{cnt.}} - T_a\right) \rightarrow \begin{cases} T_{ao} = T_{a\infty} - (T_{a\infty} - T_{ai})\exp(-\lambda_{TES}) \\ \bar T_a = T_{a\infty} - \frac{(T_{a\infty}-T_{ai})}{\lambda_{TES}}[1-\exp(-\lambda_{TES})] \\ \lambda_{TES} = \frac{(h_a+U_t)WL}{\dot m c_p} \\ L=\infty \rightarrow T_{a\infty} = \frac{h_a \bar T_{TES} + U_t T_{atm}}{h_a+U_t} \end{cases}$$

$$\frac{C}{A}\frac{d\bar T_{TES}}{dt} = \overbrace{G_T\eta_{op}}^{\dot q_{solar(t)}} - \overbrace{h_{a+r}\left(\bar T_{TES} - \bar T_a\right)}^{\dot q_{TES}=\dot Q_{TES}/A} + U_b(T_{atm} - \bar T_a) \leftarrow \text{Numerical integration}$$




Data:

$G_T = 900\ \text{W/m}^2$

$\eta_{op} = 0.7$

$\dot m = 5\ \frac{\text{g}}{\text{s}}$

$U_b = 1\ \text{W/m}^2\text{K}$

$U_t = 5\ \text{W/m}^2\text{K}$

$h_r \approx 6\ \text{W/m}^2\text{K}$

$h_{a+r} = 10\ \text{W/m}^2\text{K}$

- TES delivers comparable power after sunset than during the day

Estimated no TES cooling

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# TESTING CAMPAIGN

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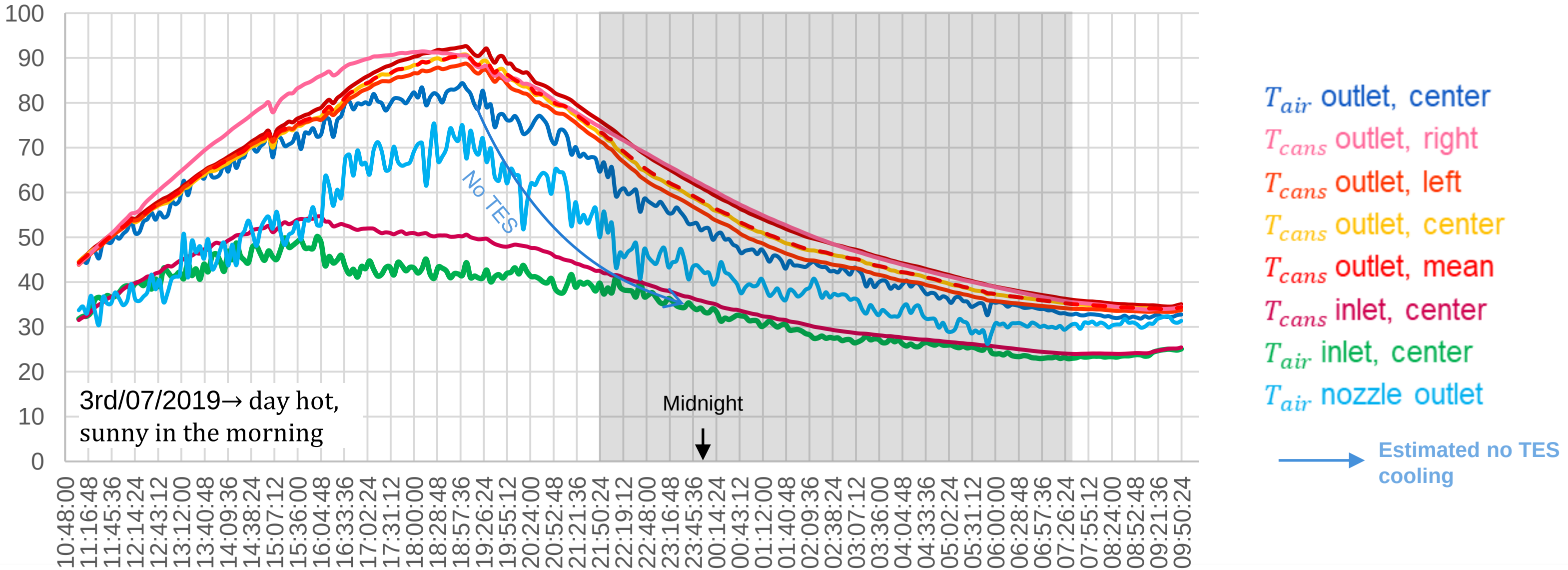
## Instantaneous measurements (smoothed) can TES collector




- More homogeneous cans outlet temperatures, and lower, owing to TES.
- Lower $T_{air}$ outlet, center owing to TES.
- Persistence of an air temperature drop in the nozzle outlet (heat losses?, air back flow?, calibration?).
- Small differences in $T_{air}$ outlet, center and $T_{cans}$ outlet, center suggests a high $h_a$.

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# CONCLUSIONS AND FURTHER WORK



- Indirect passive solar collectors seem possible and convenient for small dryers …

  … if pressure losses are limited.

- TES using drinking cans seems successful and of large potential.
- For the can flat absorber and TES there is lack of knowledge on:
  - ✓ Sun collecting capacity.
  - ✓ Pressure loss.
  - ✓ Axial temperature profile
- High wind sensitivity.

# CONCLUSIONS AND FURTHER WORK

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- Fully characterize the collector.
- Characterize the drying performances of sample foods in a cabinet.
- Test low end technologies, such as simple or dual PET film cover.
- Optimize its design (e.g., cross-section for air flow).
- Testing at field conditions, user experience.
- Determine operative life outdoors.

# Thanks for your attention!

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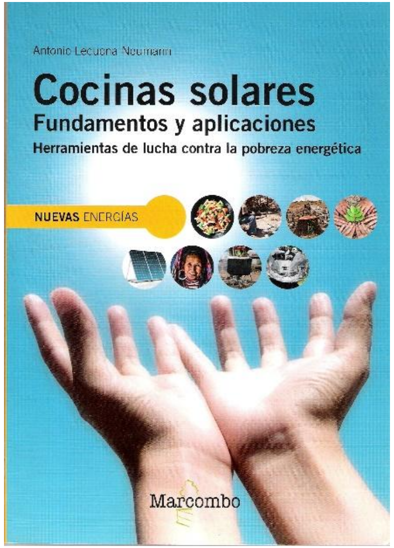


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