CONSOLFOOD 2018 Advances in Solar Thermal Food Processing

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# SOLAR COOKER AS A PUBLIC FURNITURE. THERMAL MODELING.

**Antonio Lecuona-Neumann[1*], Eduardo de la Rocha[1], José I. Nogueira[1]**

1: Grupo ITEA, Departamento de Ingeniería Térmica y de Fluidos, Universidad Carlos III de Madrid. Avda. de la Universidad 30, 28911 Leganés, Madrid, Spain. lecuona@ing.uc3m.es, http://www.uc3m.es

# Motivation

## Underdeveloped countries

- Well-known problems related with burning wood or another type of biomass

# Motivation

## What about developed countries?

- Renewable energies are increasingly present in society
- Specifically solar energy → Water heat and electricity

## Why not for cooking? → Lack of knowledge


Solar Cookers International: The Solar Cooking Wiki, http://solarcooking.wikia.com/wiki

+

Small fraction of the bill

BARRIERS

# Motivation

## Solar cookers for **developed** countries

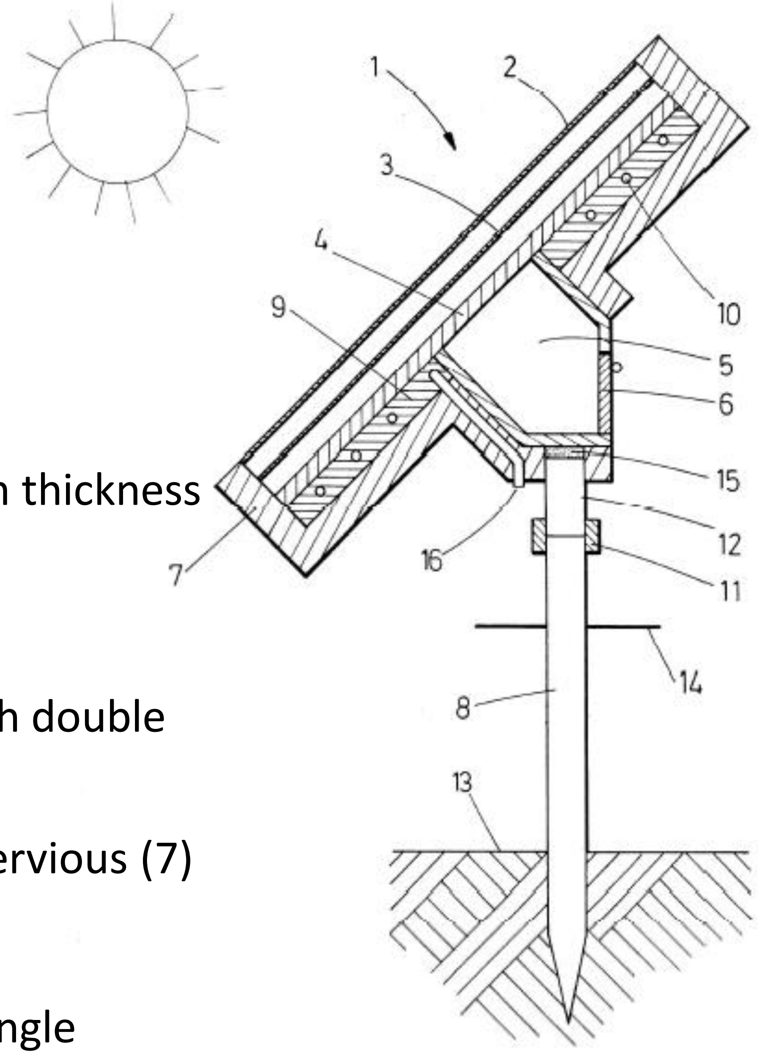
- Avoid wild fires caused by barbequing
- Avoid fumes and smells in a condominium
- Gain conscience of renewable energies and energy poverty
- Showing solar energy in public places
- Familiarize with solar energy
- Educate youth
- Induce corporate social responsibility

It could be of much help for **underdeveloped** countries

COMBINED APPROACH

# Design

- Outside location without permanent attention
- Robust and resistant to weather action
- Safe and ready to operate




- 1.5X1.5 m to 2.0X2.0 m metal absorber flat plate and around 1 cm thickness for durable heat storage (4)
- Flat glass upper cover for greenhouse effect (3), (2)
- 30 cm to 40 cm side length box soldered as ahanging oven (5) with double walled door (6)
- Thermal insulation by a thick fiberglass layer protected to be impervious (7)
- Grounded installation (13) by a supporting column (8)
- Azimuthal sun tracking (12) with lock function (11) and fixed tilt angle approximately equal to local latitude

Patented by the “ITEA” group, Carlos III University of Madrid
ES-2540160 B1; 13th April, 2016

# Design

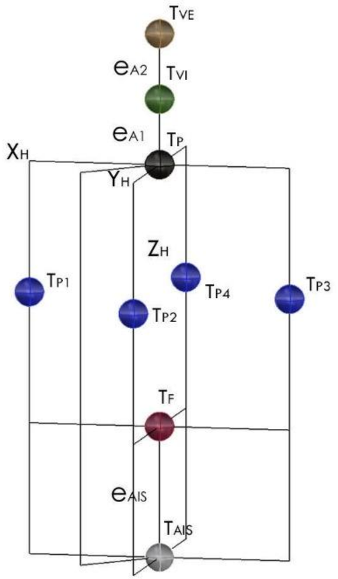
## Solar cooker as a public furniture process of development

- Thermal modeling to estimate its performances and allow to optimize the design
- Public security study and a civil regulations study
- Evaluation of a prototype including a user's and by passers survey to gather their opinion evaluation in terms of social value

# Thermal Modeling

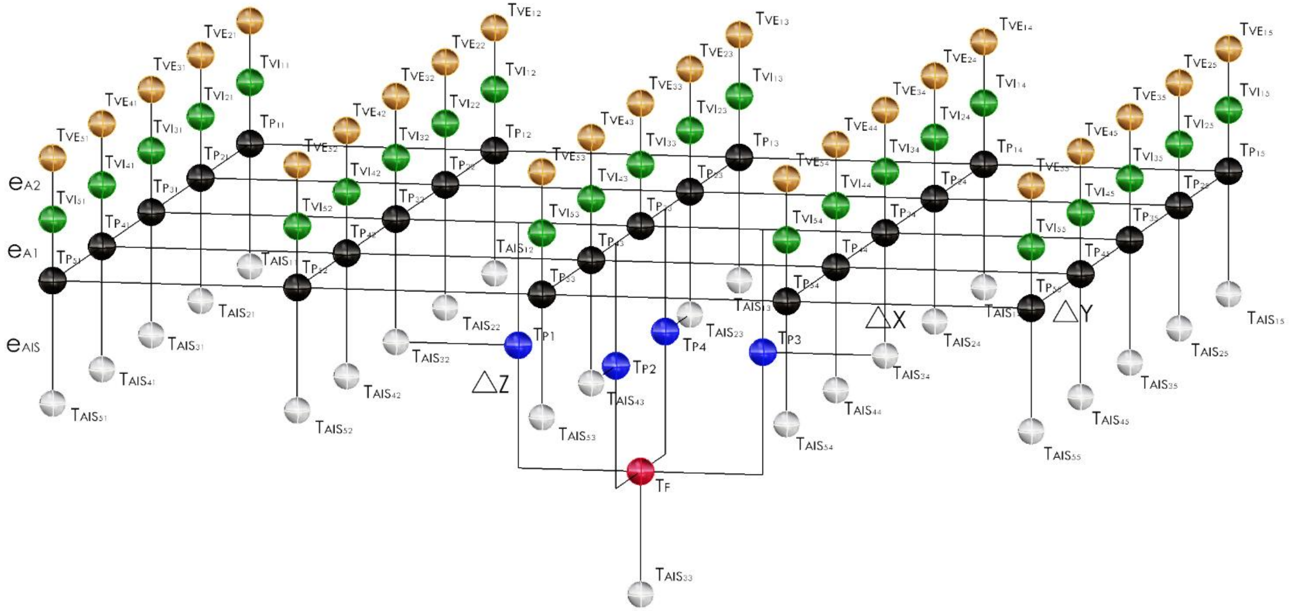
## Two approaches

- Lumped parameter 1D thermal model




Simplest modeling

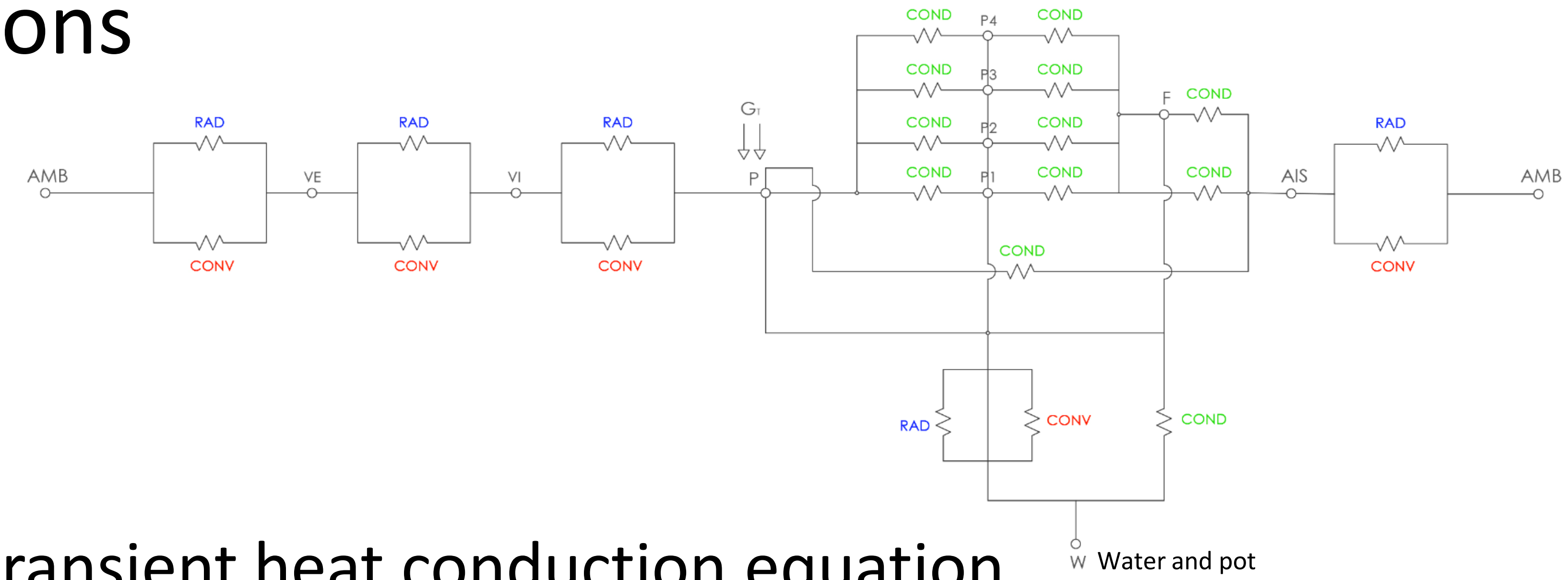
- Discretized 2D thermal model




Introduces the thermal conduction resistance in the X and Y direction ⟶ $\alpha = k\rho^{-1}c^{-1}$

# Thermal Modeling

## Equations




## Fourier-Biot transient heat conduction equation

$$\nabla^2 T + \frac{\dot{q}'''}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

- Isotropic materials
- Constant thermal conductivity
- Transitory regime

Discretized in $p \rightarrow p+1$

- Material properties
- Boundary and initial conditions

Equations implemented in Mathcad®

$$T^{p+1} = A \cdot T^{p} + B$$

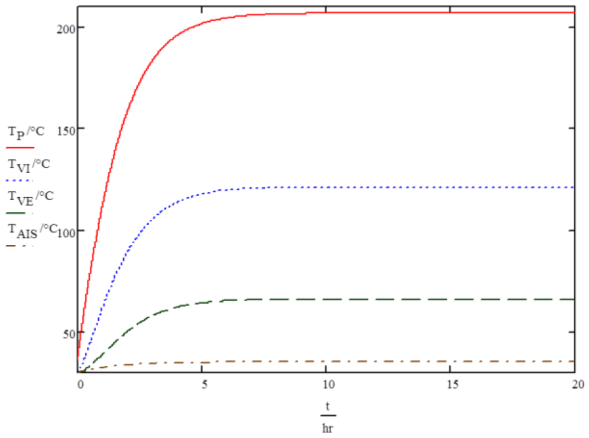
$$T_{P}{}^{p}_{\begin{cases} 0,n \\ 6,n \\ m,0 \\ m,6 \end{cases}} = T_{P}{}^{p}_{\begin{cases} 1,n \\ 5,n \\ m,1 \\ m,5 \end{cases}}$$

# Results and Discussion

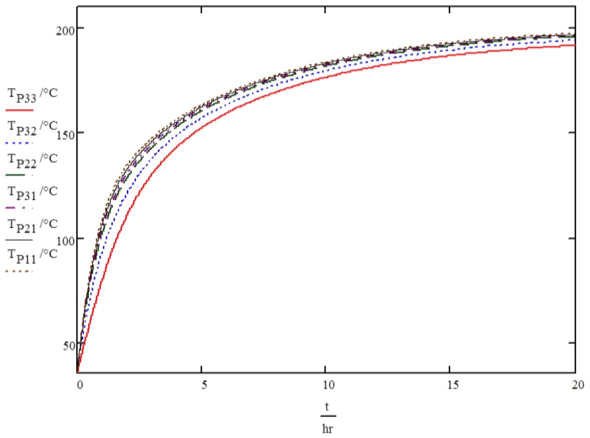
## Constant irradiance heating tests

$$G_T = 1.0\ \mathrm{kW\ m^{-2}} \qquad T_{AMB} = 30\ ^{\circ}\mathrm{C}$$

- Time evolution of temperatures during no load test under constant irradiance

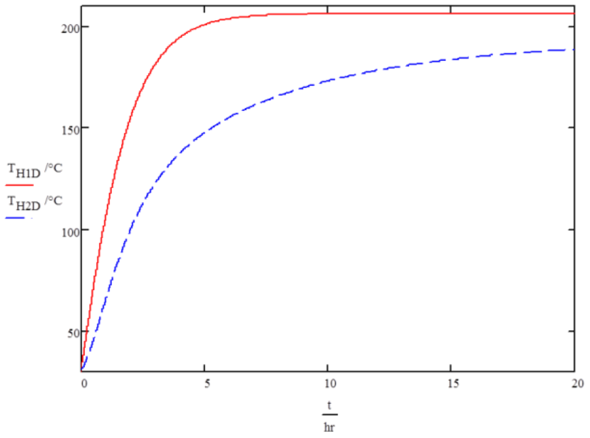



Main temperatures of the 1D model

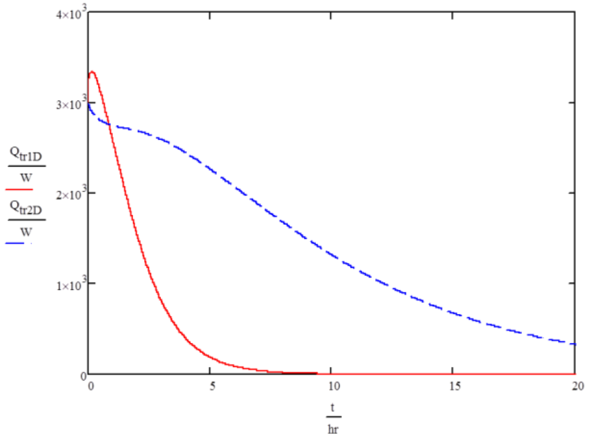



Temperature of some of the absorber plate elements of the 2D model

- Comparison of time evolution during no load heating




Temperature of the bottom wall of the oven $T_H$



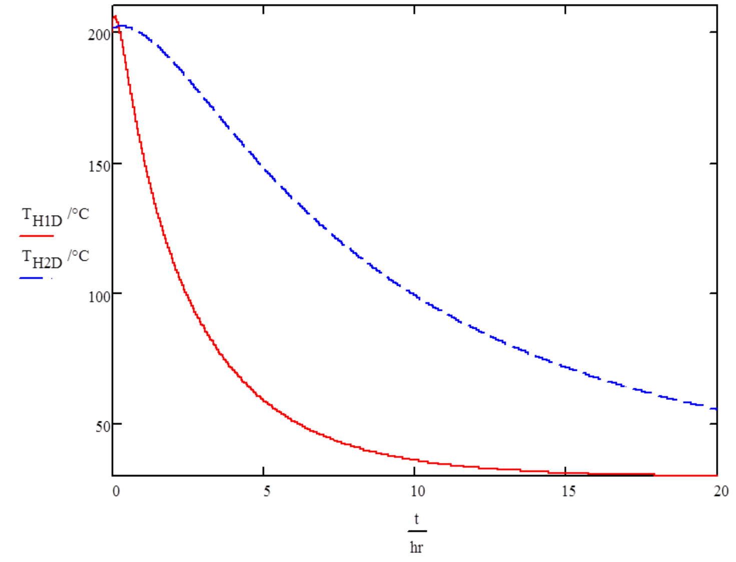

Total power time evolution

# Results and Discussion

## Constant irradiance cooling tests

$G_T = 0 \qquad T_{AMB} = 30\ ^{\circ}\text{C}$

- Temperature time evolution during no load cooling of the bottom wall of the oven $T_H$

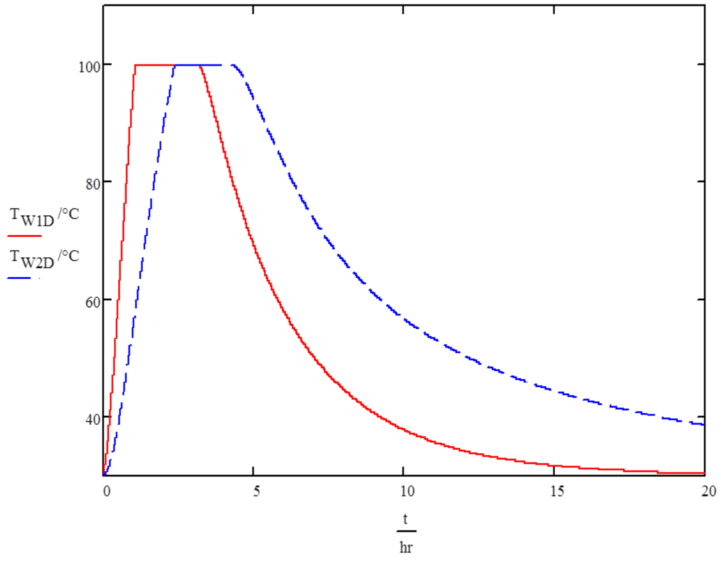



$t^*_{en0D\,H} = 2{,}73\ \text{h}$

$t^*_{en2D\,H} = 10{,}94\ \text{h}$

$G_T = 1.0\ \text{kW m}^{-2} \qquad T_{AMB} = 30\ ^{\circ}\text{C}$

- 2 kg water load heating with boiling and cooling




$t^*_{en0D\,W} = 4{,}18\ \text{h} \quad Q_{W0D} \cong 175\ \text{W}$

$\dot{m}_{eb0D} = 1.250\ \text{g h}^{-1}$

$t^*_{en2D\,W} = 6{,}82\ \text{h} \quad Q_{W2D} \cong 81\ \text{W}$

$\dot{m}_{eb2D} \sim 448\ \text{g h}^{-1}$

# Results and Discussion

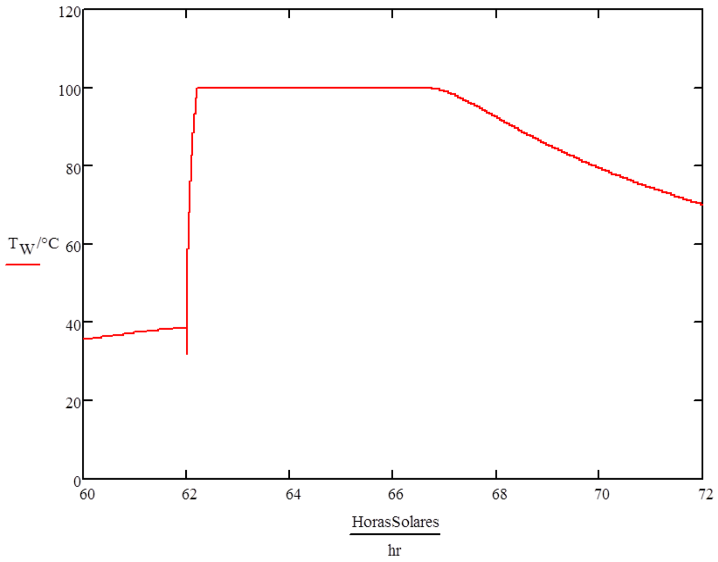
## Clear day tests

- Water temperature time evolution, 2D model, starting with 2 kg water load in the afternoon after 3 days of equalization

$G_{T,\max} = 925\ \mathrm{W\,m^{-2}}$

$T_{MAX} = 40°C$ at 4:00 pm, solar time

$T_{MIN} = 23°C$ at 4:00 am, solar time




June, Madrid

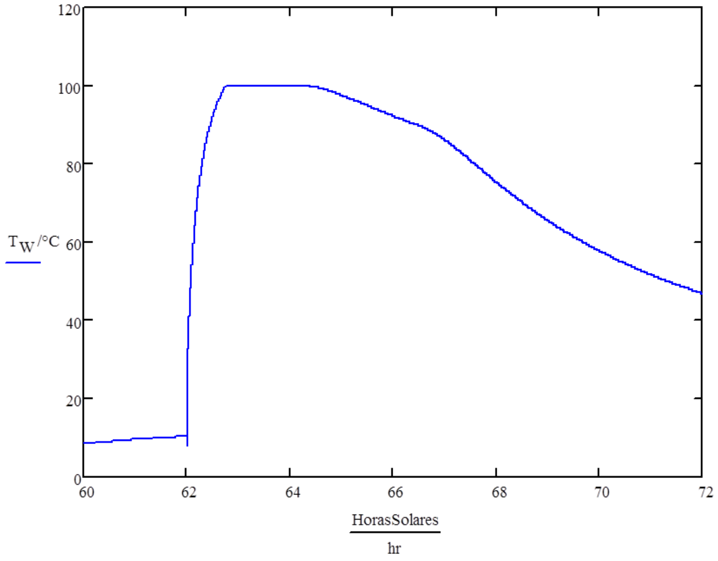
$t_{ebMIN} = 12$ min at 14:00 pm, solar time

$t_{eb} = 31$ min at 17:30 pm, solar time

$G_{T,\max} = 802\ \mathrm{W\,m^{-2}}$

$T_{MAX} = 11\ °C$ at 4:00 pm, solar time

$T_{MIN} = 1\ °C$ at 4:00 am, solar time




January, Madrid

$t_{eb} = 46$ min at 14:00 pm, solar time

# Conclusions

- An innovative solar cooker-oven as a public furniture has been proposed
  - Permanently outdoors with minimum maintenance
  - It incorporates sensible heat storage into its own solid-state materials
- The performed thermal modeling promises good performances, supporting the concept
  - It can cook lunch and dinner during the whole year during a clear day at mid latitudes
- The heat diffusivity of the absorber plate plays an important role in the oven temperature time evolution
  - 2D modeling can represent this phenomenon but not 1D modeling
  - The 1D model needs some improvements if better predictions are expected

# Future Modeling Improvements

- Introduce a phase change material (PCM) between the collector-oven assembly and the thermal insulation and analyze its response in order to accumulate heat for more hours and be able to prepare breakfast

- Analyze the performance with cheaper materials and other food

- Improve the accuracy of the 1D model and validate experimentally

# Thank you very much for the attention