AESCA/AECID/CYTED

Jornada de Cocinas solares

Cocinas Solares como herramienta de la lucha contra la pobreza energética

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Energy for cooking

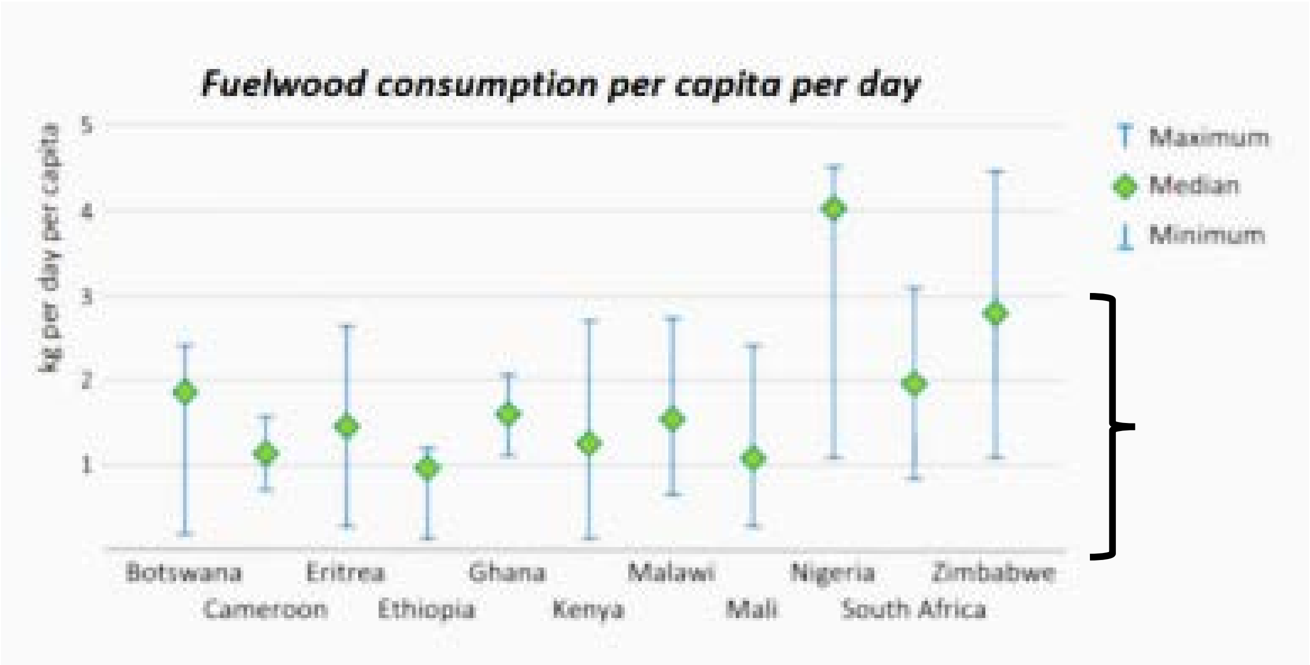
- In our countries we can cook with the sun, but this is only anecdotic, as the energy expenses for cooking are negligible in front of other uses.
- Electrical Cooking (e. g.) includes some “solar” Cooking because of solar powerplants.
- But …
  - 13% of human kind lacks Access to modern forms of energy OR IT CAN BE COSTLY AND/OR UNRELIABLE.
  - This obliges 3 billion people to cook with biomass (firewood, dung and agricultural residues).
  - This brings many problems, like:
    - Pollution.
    - Deforestation.
    - Delay in development because of the time required to collect biomass.
  - Sub-saharan overall population growing four times faster than the population that gained access to clean cooking technologies between 2014-2016.

One reference: TRACKING SDG7: THE ENERGY PROGRESS REPORT 2018 International Bank for Reconstruction and Development / The World Bank

Energy for cooking, ¿can families afford it?

- Consumo de entre 1 y 3 kg de leña por persona y día. A unos 25 MJ/kg al 15% de eficiencia (puede ser menor) hace:
  - 5 a 15 Kwh por familia de 5 personas.
  - Con un 50% de eficiencia son 0,8 a 2,5 litros de queroseno o propano
  - Probablemente no es solo para cocer.

} Excesivo!

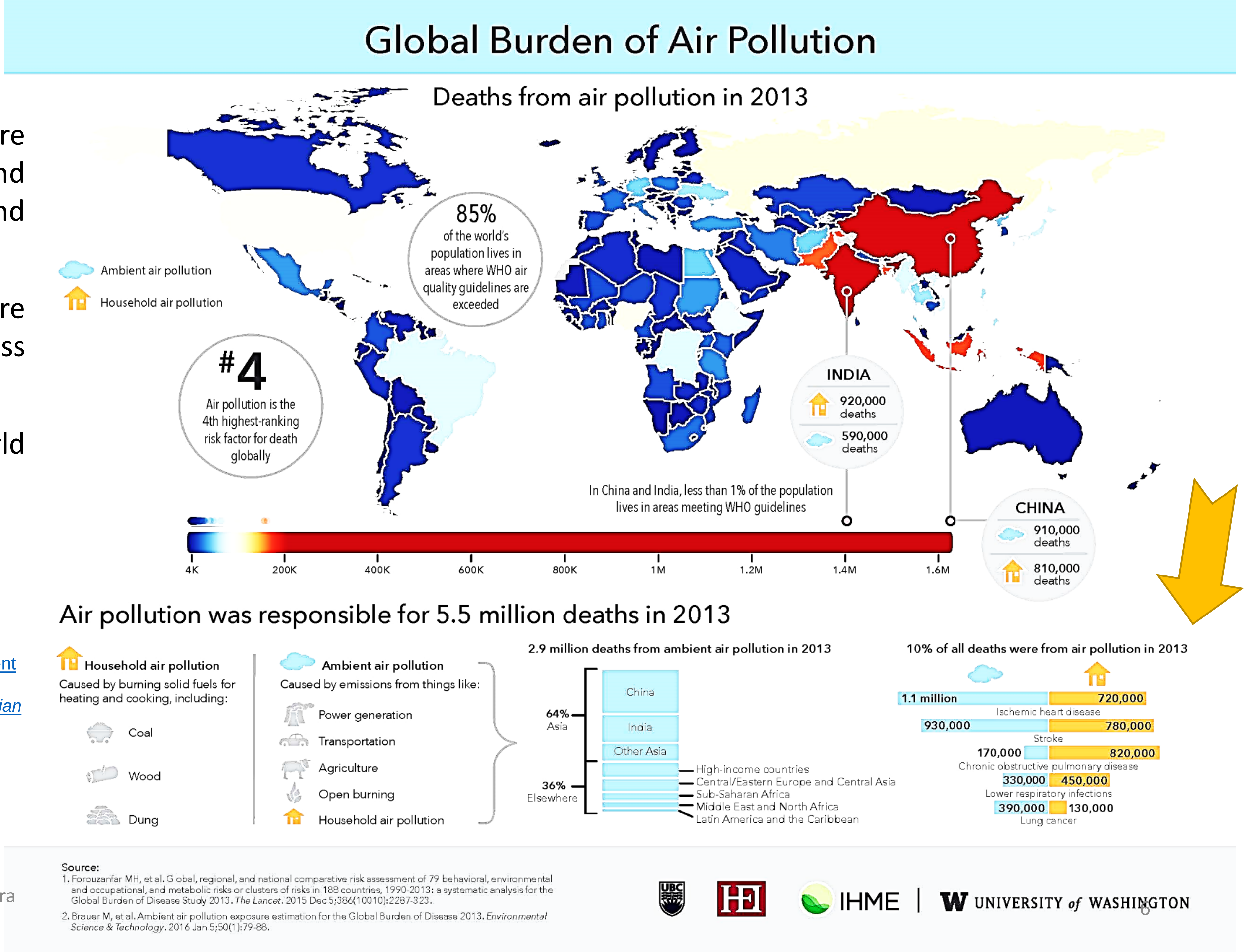


Indoor (and outdoor) pollution because of fumes

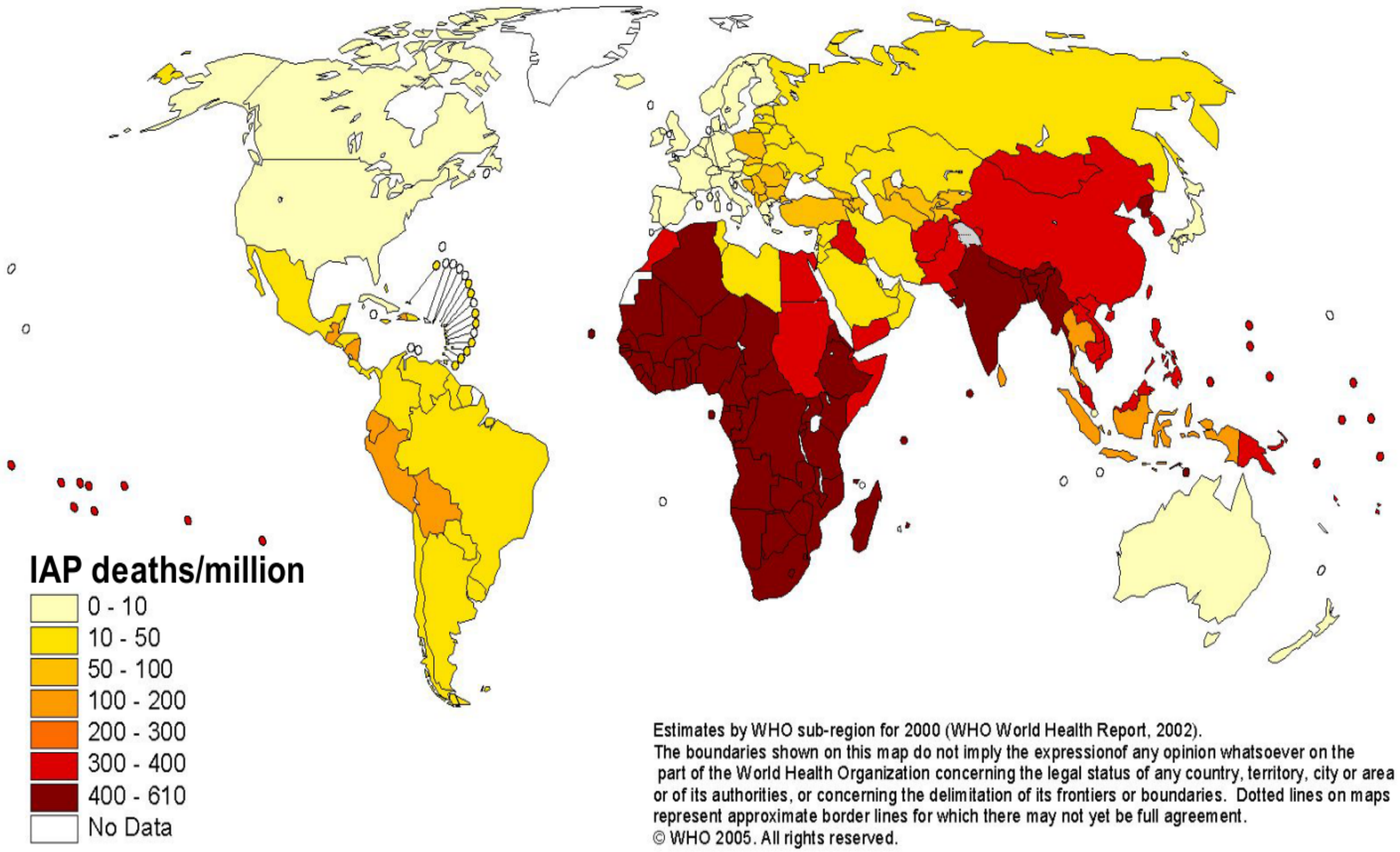
- Bad combustion and low efficiency cookstoves, no chimney.
- Long term breathing polluted air causes illnesses: heart, stroke, pulmonary diseases, cancer, ...

Cocina solar como instrument de lucha contra la pobreza energética, A. Lecuona, UC3M

- 5.5 million annual premature deaths from indoor and outdoor pollution, Asia and China especially.
- From them, 2.9 million are caused by burning biomass indoors.
- Data from WHO (World Health Organization).
- More data:
  - [Global Health Observatory]
  - [Boman, B., Forsberg, A., & Järvholm, B. (2003). Adverse health effects from ambient air pollution in relation to residential wood combustion in modern society. *Scandinavian Journal of Work, Environment & Health, 29*(4), 251-260.]



Indoor Air Pollution deaths



The problema is escalating "**deaths** due to**IAP from** biomass fuel use has been projected at 9.8 **million by** the year 2030 (Bailis et al., 2005)". https://books.google.es/books?isbn=1439809631

More problems from cooking with biomass

Painful firewood collection. Excessive time consumption. Risks, accidents.

- Largas horas de caminata
- Pérdida de escolaridad
- Riesgo de accidente
- Riesgo de ataques, robos, secuestros y violaciones
- Lesiones de cuello y espalda

More problems from cooking with biomass

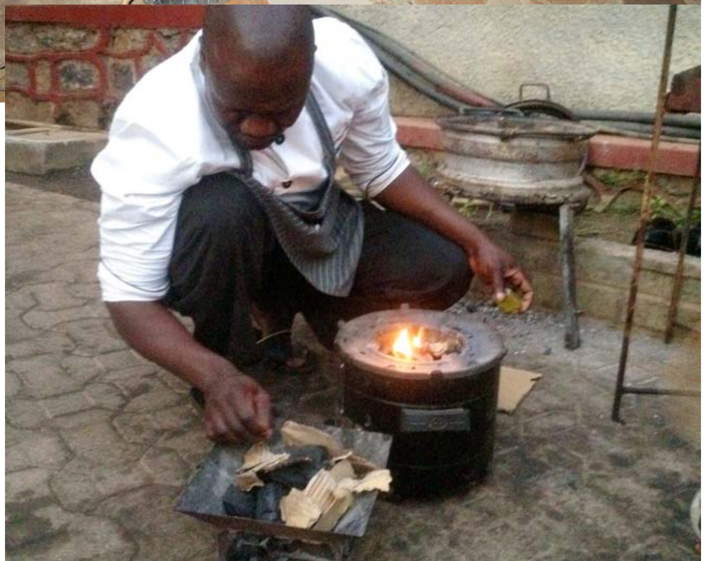
- Charcoal production is even worse

Se pierde 2/3 del poder calorífico de la leña con el carboneo. Pero se logra un combustible más ligero, con menos humo e inerte

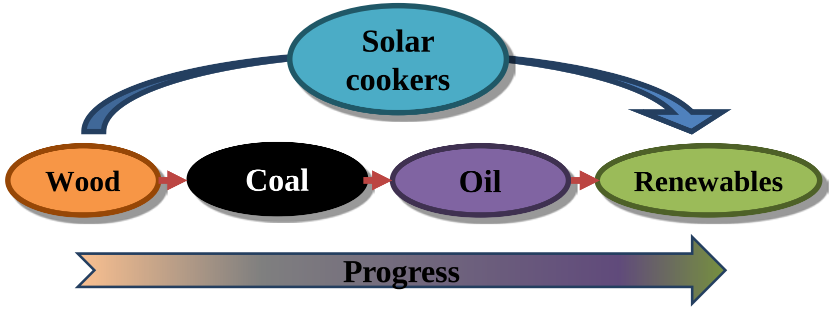
- Deforestation

Alleviating the problems

- Improved cookstoves are being proposed



- Solar thermal cookers are well known



Limitations of solar thermal cookers

- Cooking outdoors and only during sunny periods of the day.
- Cooking dinner and breakfast is not possible.

Excepting by the use of heat insulating “Hay baskets”
HEAT RETENTION COOKING ↓

Limitations of solar thermal cookers

- Dinner and breakfast cannot be cooked, because of the absence of sun.
- Cooking outdoors causes contamination, social problems and animal threats, thefts.
- Wind can spoil the cooked meal and the solar cooker.
- Incompatibility with traditional cooking practices and reluctance to change.
- Difficult to handle, too bulky.
- **Risk of failure in cloudy weather. Can be only of help.**
- Continuous care. Too slow.
- Tendency to return to "traditional cooking".

- Difficult or impossible in peri-urban areas, no sunny space.
- Non available in the local market.
- High procurement cost. No funding.

Why PV solar cookers?

- There is an expanding market of electronics and telecommunications.
- The price of PV panels has fallen dramatically, now $\sim 0.5\ €/\mathrm{W_p}$.
- Nano-power and nano-technology offer promises of innovations and growth.

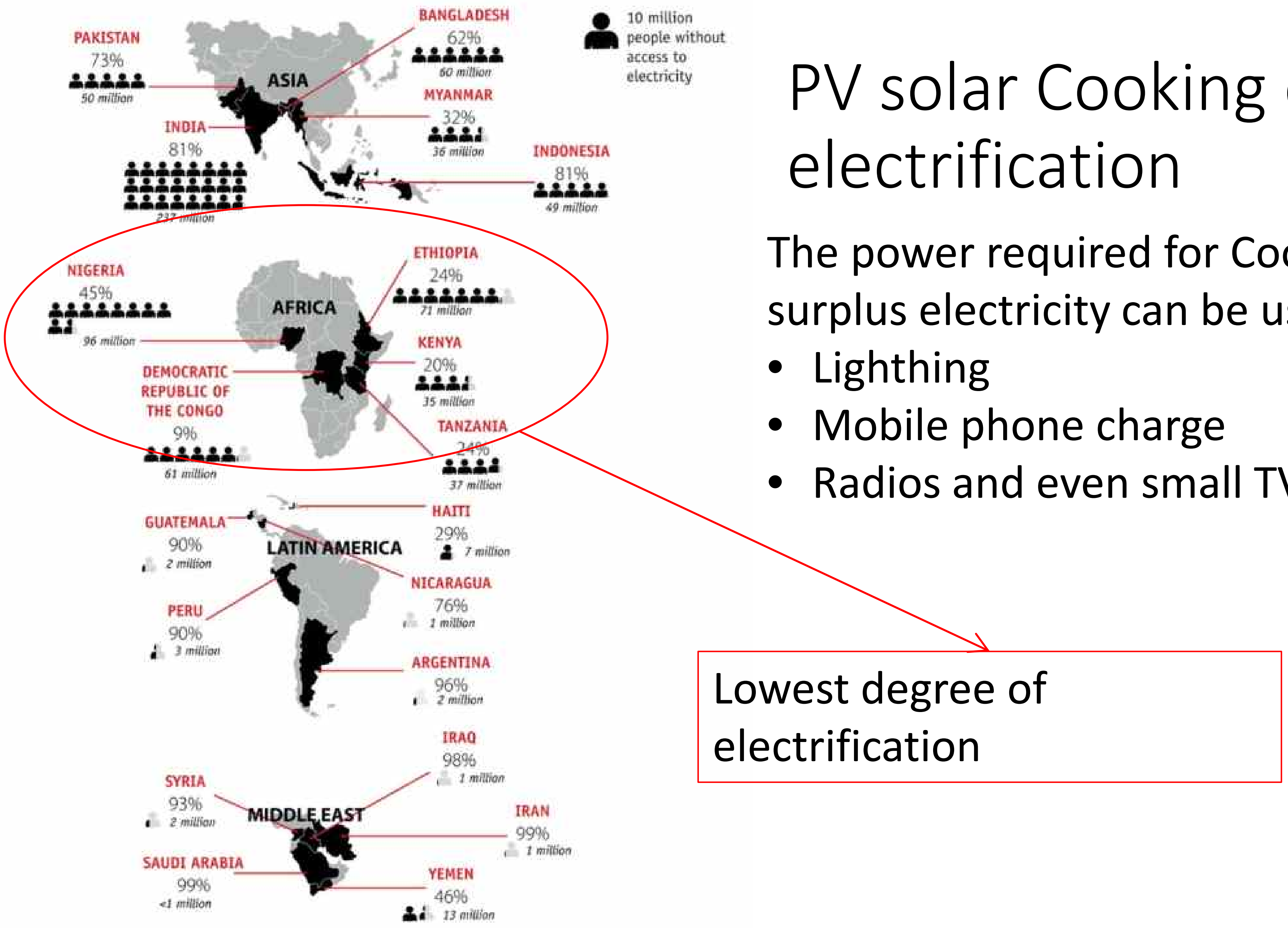
There are now actions to introduce nano-PV systems to fight energy poverty, e. g.:

M-KOPA 5 Control Unit with Lithium Battery
8 W Solar Panel
4 Bright, 1.2 W LED Bulbs
Rechargeable Torch
Rechargeable FM/USB Radio
5-in-1 Phone Charge Cable
Custom Charge Cable
Source: http://www.m-kopa.com/products/

Pay-As-You-Go (PAYG) program in Africa. Business model, a company essentially rents consumers a solar home system that comes with a battery, a charge controller, a solar panel, LED bulbs and a mobile charger.
Alleviates funding
Photo by Russell Watkins/DFID.

An estimated 1.2 billion people—17% of the global population—did not have access to electricity in 2013, the latest data from the International Energy Agency show. More than 95% of those living without electricity are in countries in sub-Saharan Africa and developing Asia, and they are predominantly in rural areas (around 80% of the world total). Here are five countries per region (developing Asia, Africa, Latin America, and the Middle East) that have the largest populations without access to electricity. Also noted is that country's national electrification rate (%). Source: IEA, World Energy Outlook 2015

—*Copy and artwork by Sonal Patel, a POWER associate editor*



Why PV solar cookers?

PV solar Cooking can help electrification

The power required for Cooking is high so that surplus electricity can be used for:

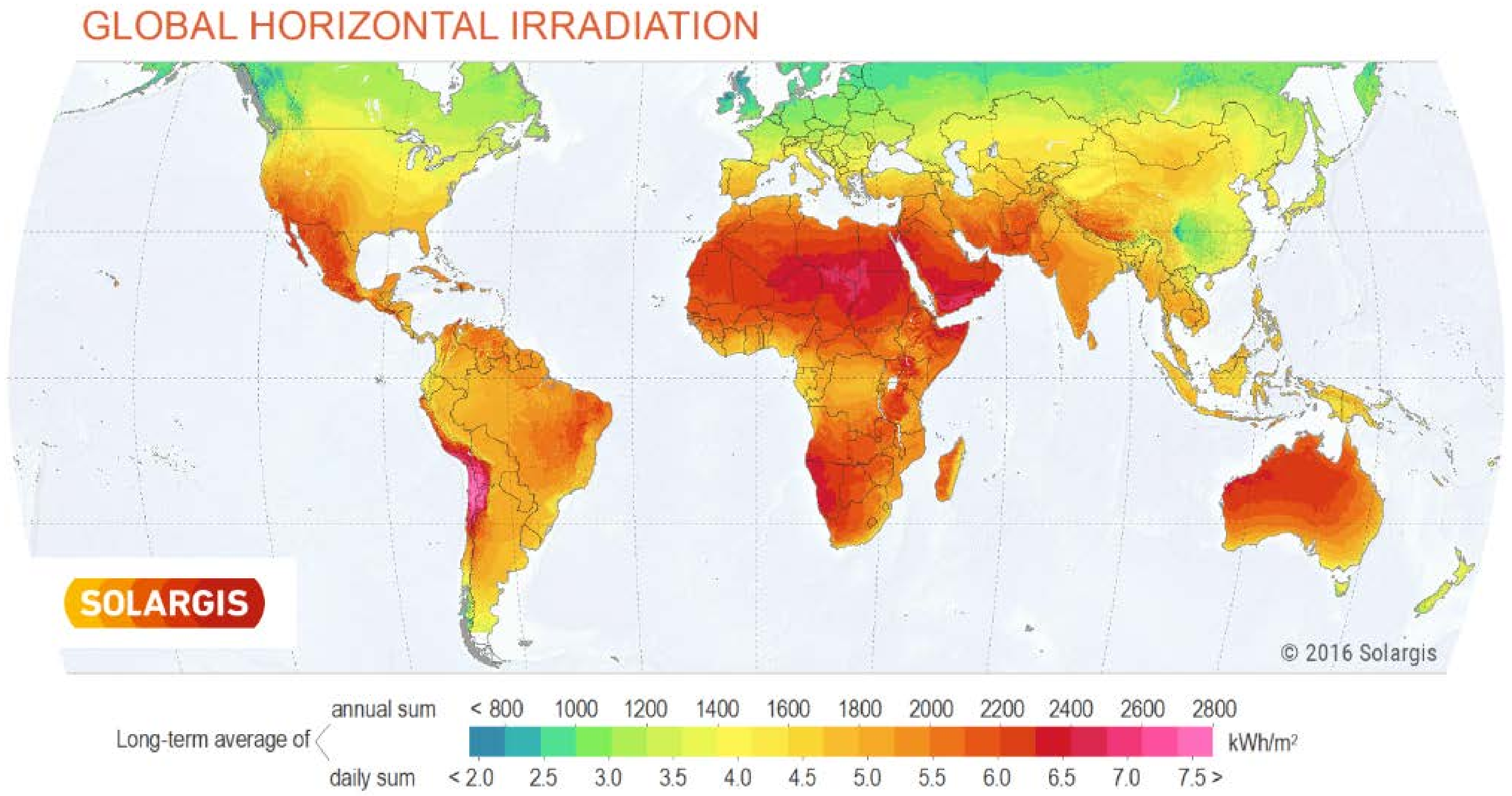
- Lighthing
- Mobile phone charge
- Radios and even small TVs.

Why PV solar cookers?

- Is PV solar cooking possible for a family?

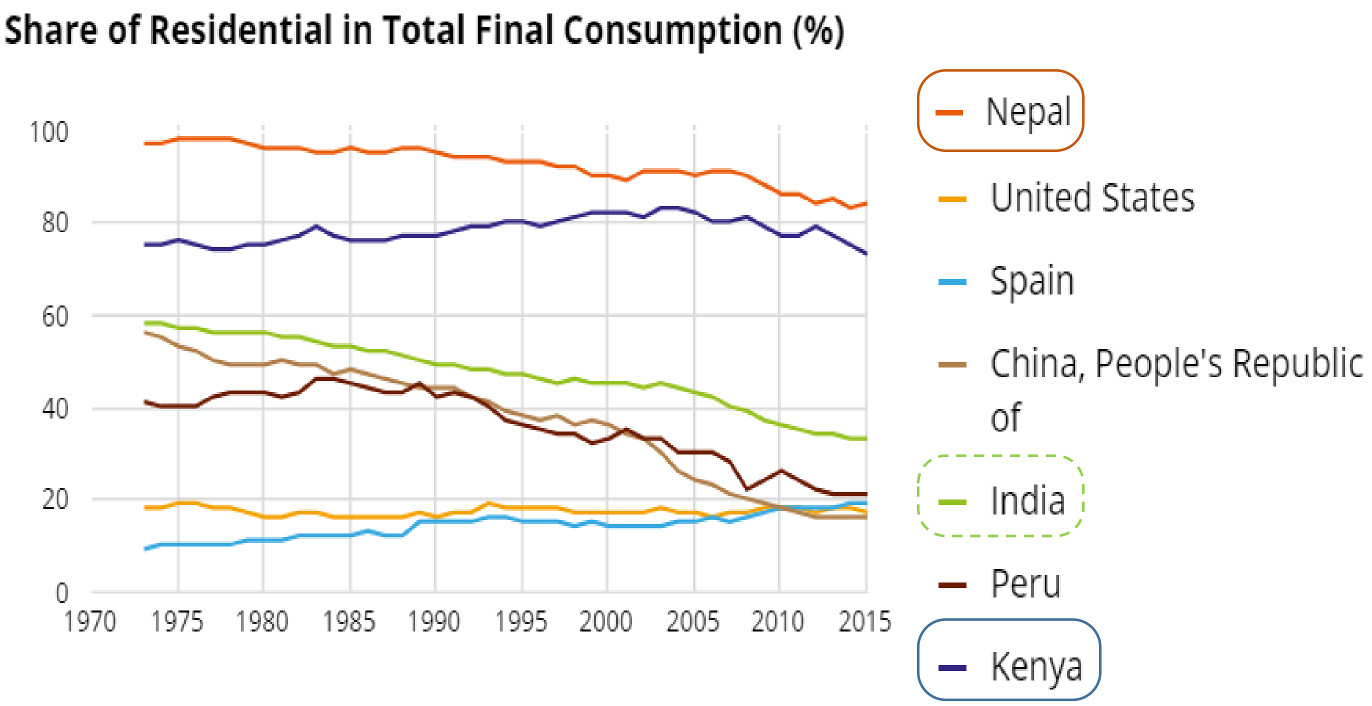
$A_a = 2\ \mathrm{m}^2$ PV panel of $300\ \mathrm{W_p}$ yields in 1 average day an energy in kWh, considering 18% total system losses, no tracking:

Madrid	Argelia	Sudan	Central India	Central China	Average kWh
1.5	1.6	1.5	1.3-1.7	0.8-1.7	1.5



- Heating 2 kg of water from 15 ºC up to 100 ºC consumes 0.2 kWh.
- From another point of view solar thermal cookers have about 1.2 m² of aperture and an efficiency $\eta \sim 0.25$. PV has $\eta \sim 0.15 \rightarrow 2\mathrm{m}^2$ seems reasonable .
- There are single PV panels of 2 m².

Will the impact of renewable residential energy be large?



"IEA Statistics: Energy Atlas", International Energy Agency. http://energyatlas.iea.org/#!/tellmap/-1002896040/4

Residential:

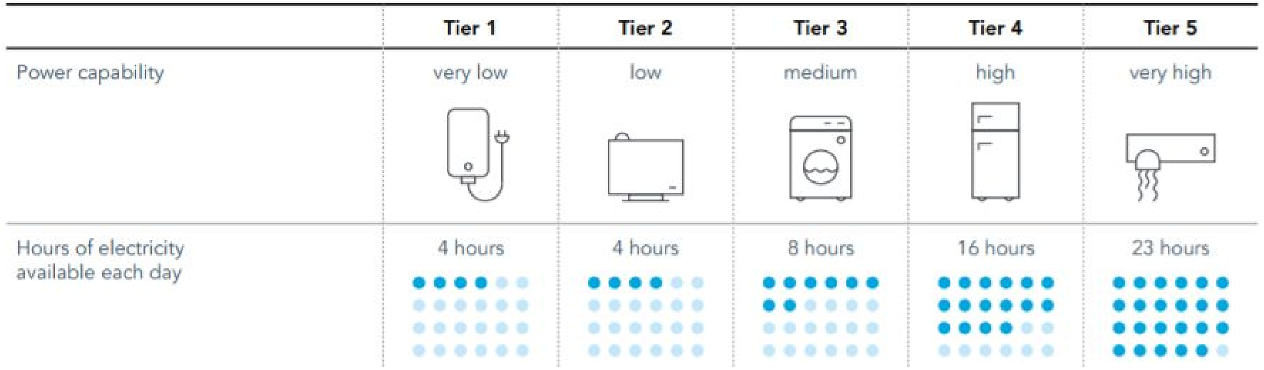
- Space Heating
- Cooking
- Lighting
- Appliances

According to "*Medios, Noticias: Una dendroenergía más ecológica es clave para mitigar el cambio climático y mejorar los medios de vida rurales*", FAO, 21-03-2017 http://www.fao.org/news/story/es/item/853537/icode/ :

-- 7% of the anthropogenic World emissions of greenhouse effect gases are caused by the combustion of firewood and charcoal --

Decentralized rural electrification, why?

- Micro grids are Combustion based, Hydroelectric and more widely available: solar.
- Lighting and mobile charging is quite simple, cooking and refrigerating needs more power.
- Levels:

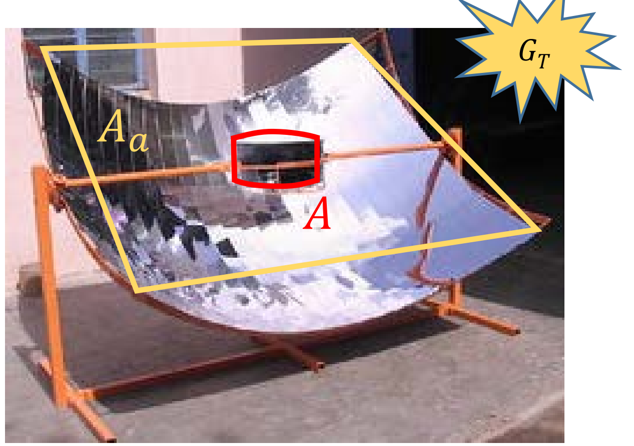


- Contribute to 8 of the 17 the "Sustainable Development Goals" , *ODS de la Agenda 2013*.

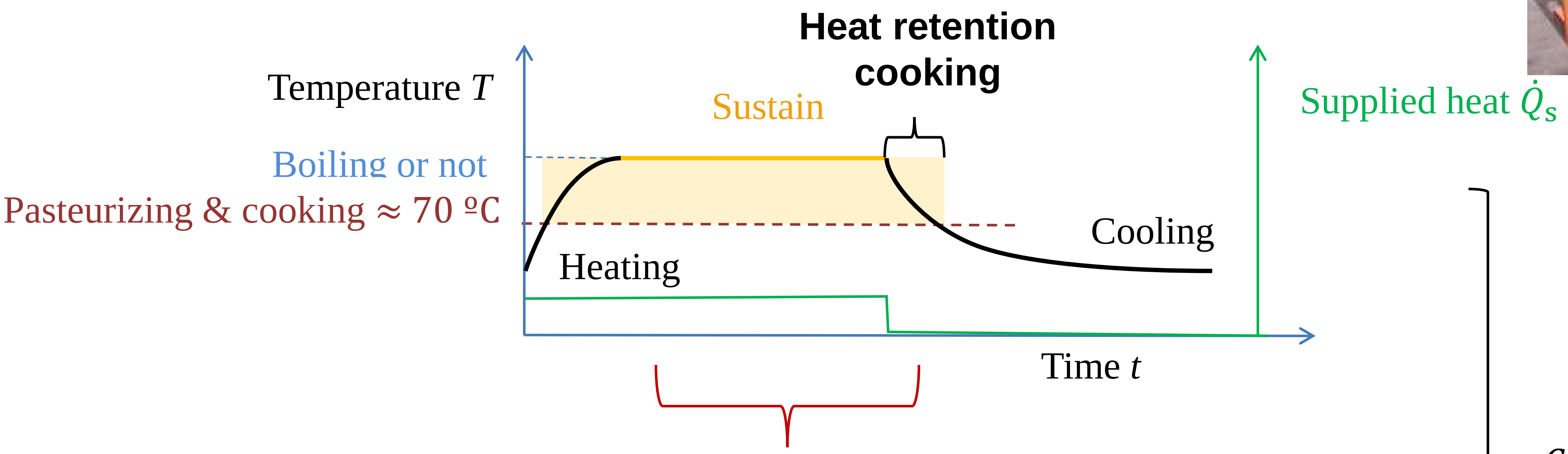
1. NO POVERTY.	ZERO HUNGER	3. GOOD HEALTH & WELL-BEING	4. QUALITY EDUCATION	7. AFFORDABLE & CLEAN ENERGY	8. DECENT WORK & ECONOMIC GROWTH	10. REDUCED INEQUALITIES	13. CLIMATE ACTION

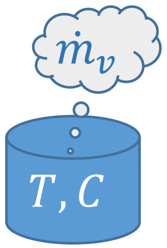
- From: *2017. UN Climate Change Conference in Bonn, Germany, Sustainable Energy for All (SEforALL) and Power for All. Why Wait?*
- It costs less than grid access in remote areas.
- It prepares for full electrification.

Cooking process, direct solar



- Chemical energy change is negligible





Only steady-state heat losses:

- Sensible: $\dot{Q}_{se} = UA(T - T_{amb})$
- Latent (boiling): $\dot{Q}_{l,boil} = \dot{m}_{v,boil} L$
- Latent (evaporation): $\dot{Q}_{l,nboil} = \dot{m}_v L; \dot{m}_v = K A_{ev}(P_v - \Delta P - P_{v,amb}) < \dot{m}_{v,boil}$

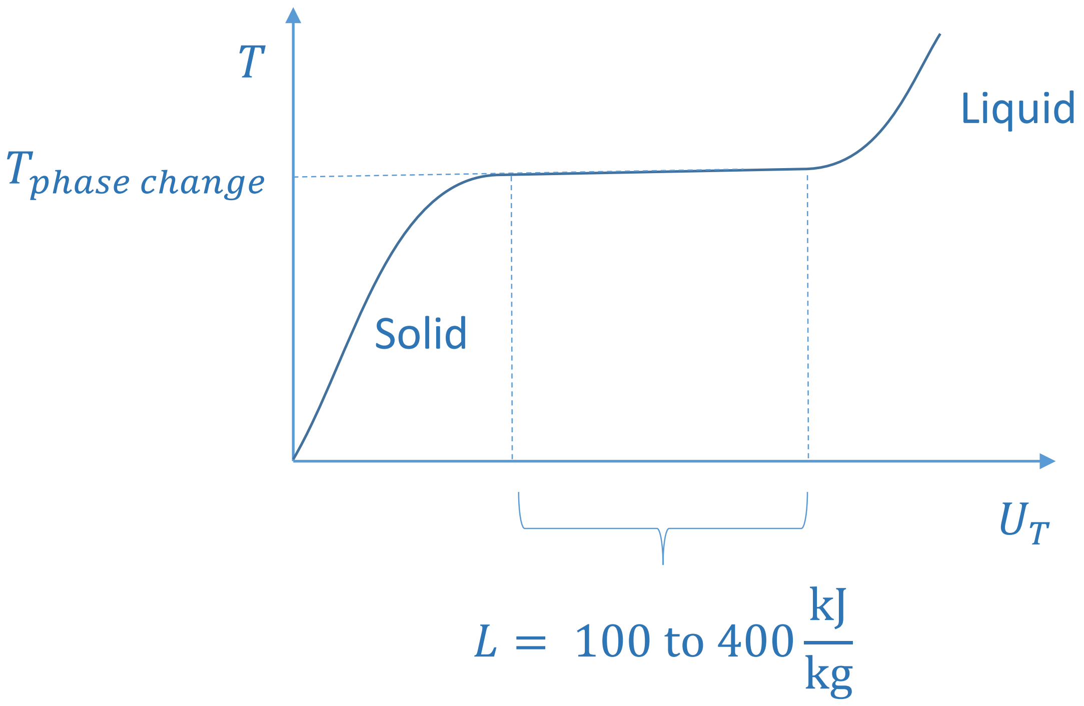
Transient model

$$C \frac{\mathrm{d}T}{\mathrm{d}t} = \underbrace{A_a G_T \eta_{op}}_{\substack{\text{Solar power} \\ \dot{Q}_s}} - \dot{Q}_{se} - \dot{Q}_l$$

- Water evaporation and heat transfer to ambient should be minimized. Boiling is not needed! → slow cooking.

Cooking process, indirect

PCM: Phase Change Material. E. g. Ice, parafins, hydrated salts,



Desired:

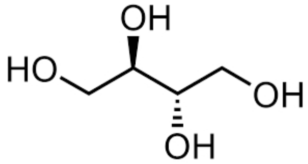
- $T_{phase\ change} > 100$ ºC for boiling
- $T_{phase\ change} > 200$ ºC for frying
- High phase change Heat L
- Non-toxic
- Non-corrosive
- High Heat conductivity
- Long lasting.
- Low cost

$$\dot{Q} = L\frac{dm_{phase\ change}}{dt} \rightarrow \text{to the food}$$

Heat retention Cooking (high insulation) with Thermal Energy storage (TES) using PCMs seems a good choice! THERMAL BATTERY

Thermal storage using a Phase Change Material (PCM)

- Phase change allows to store more heat, but melting temperature must be high enough.
- Must be non-corrosive, non-toxic, low cost ~ 6 €/kg.
- Erythritol edible four-carbon polyol is a good candidate.
- It is considered a non-caloric sugar



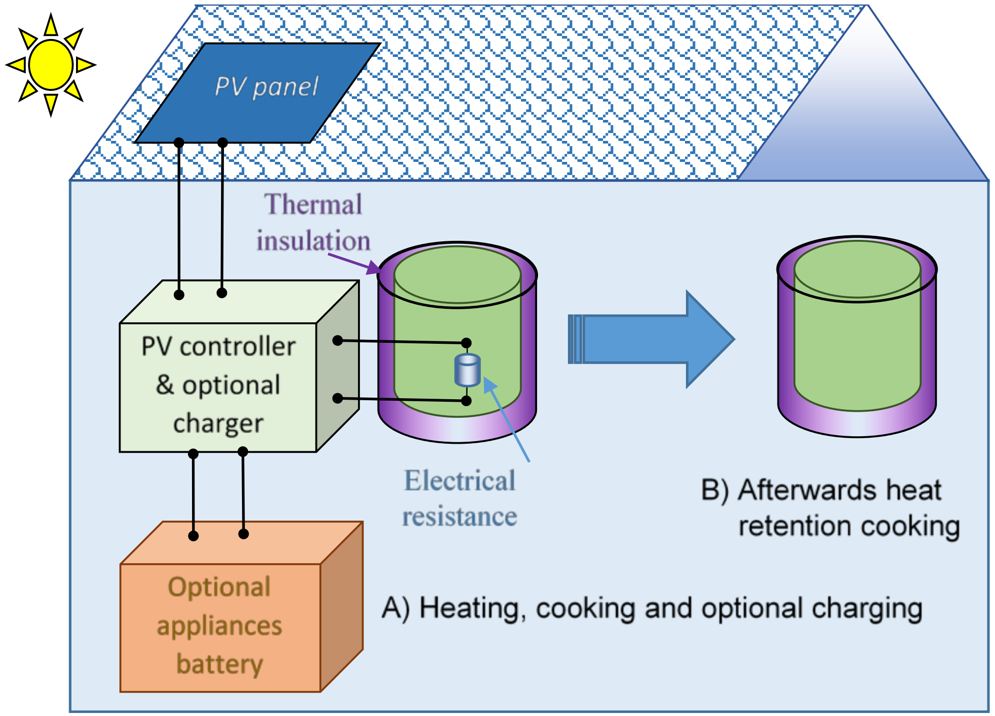
	Heat conductivity solid/liquid [W m^{-1} K^{-1}]	Density solid/liquid [kg m^{-3}]	Melting heat @ T [J g^{-1}] @ [ºC]	Specific heat solid/liquid [kJ kg^{-1} K^{-1}]
Erythritol	0.733/0.326	1,480@25ºC/1,300@120ºC	340 @ 118 ºC	1.38/2.76

↑ Too low, but enhancement is possible …

Similar to ice → 2kg stores 0,24 kWh

Family size PV solar cooking proposal

- Large batteries are too expensive, polluting and too heavy. Instead thermal storage.
- DC/AC converters (inverters) are not needed → Direct 24 V DC coupling with a resistance for heating.
- In addition, a $2\ \mathrm{m}^2$ 300 W_p panel allows charging lighting, mobiles and other small appliances batteries.



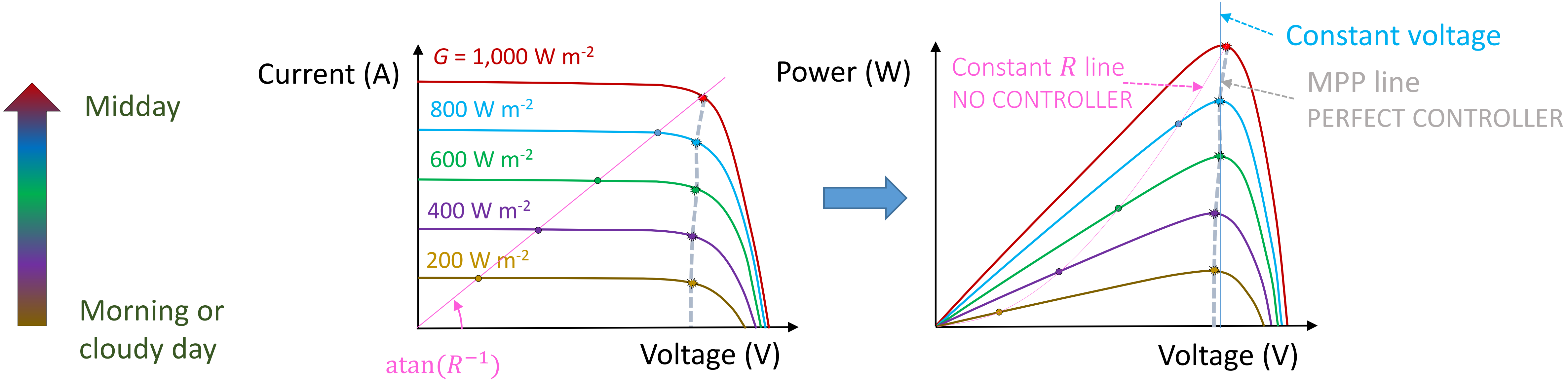
Cost breakdown Item	Off the shelf cost (€)
PV panel	150-300
Installation & training	30
Controller	10
Cables & plugs	10
Electronic pot*	30
DC resistance	10
TOTAL AVERAGE $C_0 =$	330

With a factor 2.0 for financing & maintenance: $LCOE = \frac{330\ €\times 2.0}{20\ \mathrm{years}}\left(1.5\,\frac{\mathrm{kWh}}{\mathrm{day}}\,365\,\frac{\mathrm{day}}{\mathrm{year}}\right)^{-1} = 6\,\frac{\mathrm{c€}}{\mathrm{kWh}}$ in a per day use – COMPETITIVE

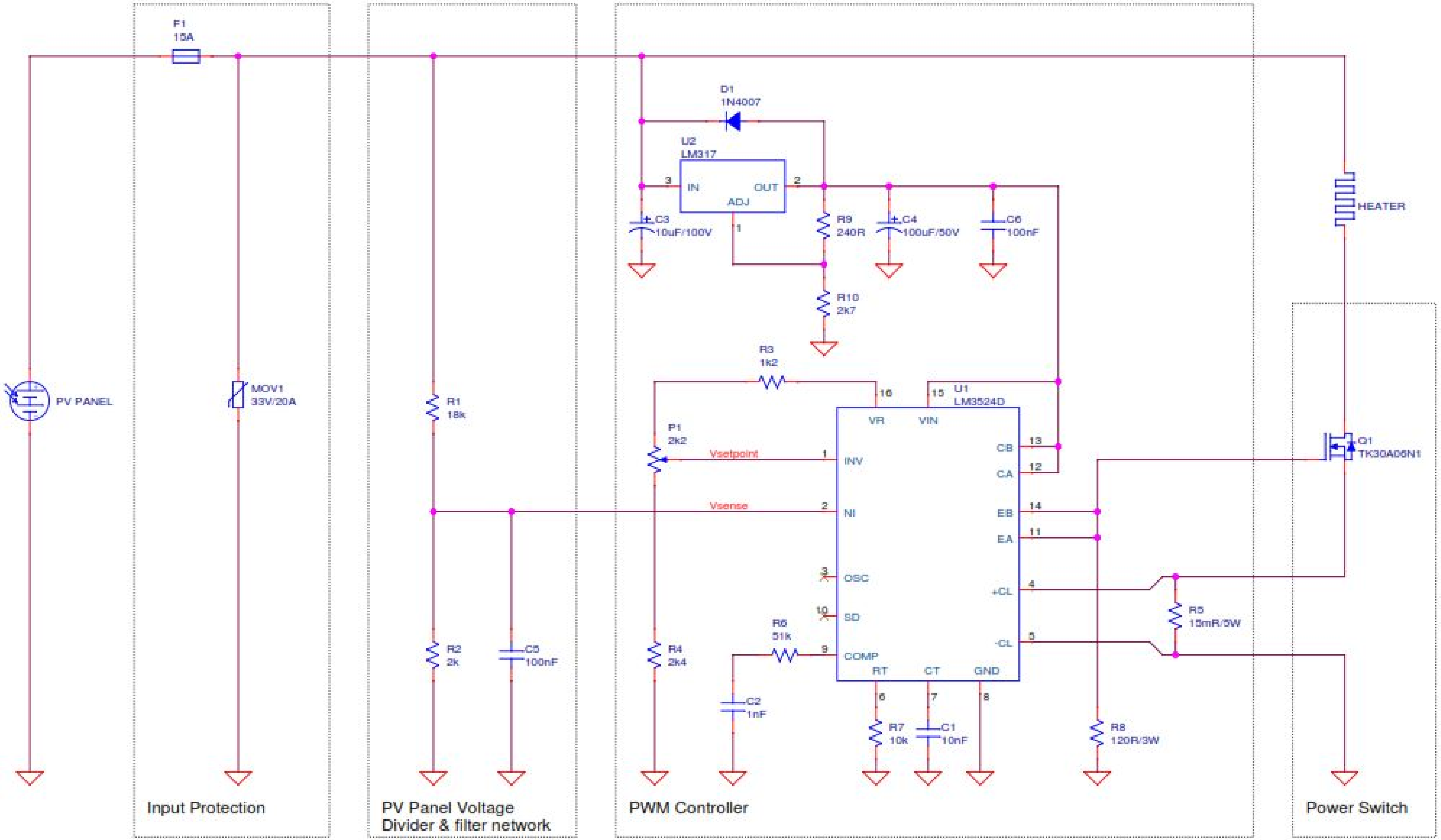
Family size PV solar cooking proposal. Control.

- PV panels require a “controller” circuit owing to the generating characteristics of PV cells and the variable solar irradiance G.
- Conventional PV controllers use the battery as an intensity sink with relatively constant voltage.
- There is need of an “appropriate technology” PV controller:
  - Low cost.
  - *In situ* constructed, maintained and repaired.

PRINCIPLES: Under standard testing conditions, 25 ºC, no aging, no silt the PV panel performances are:



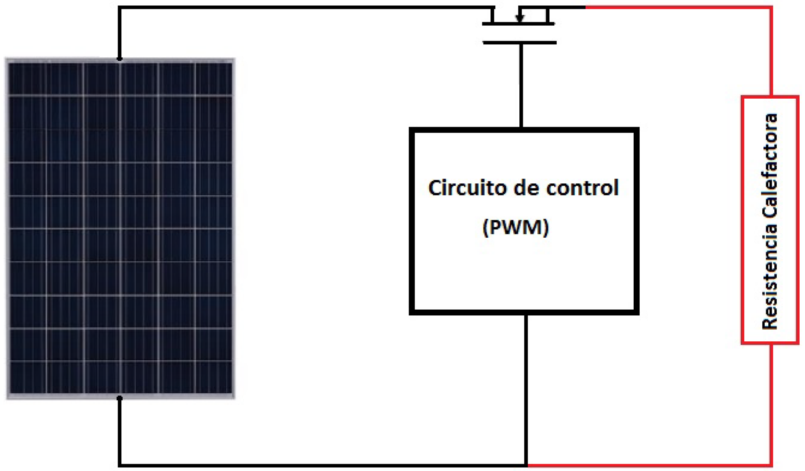
Very simple PV controller circuit

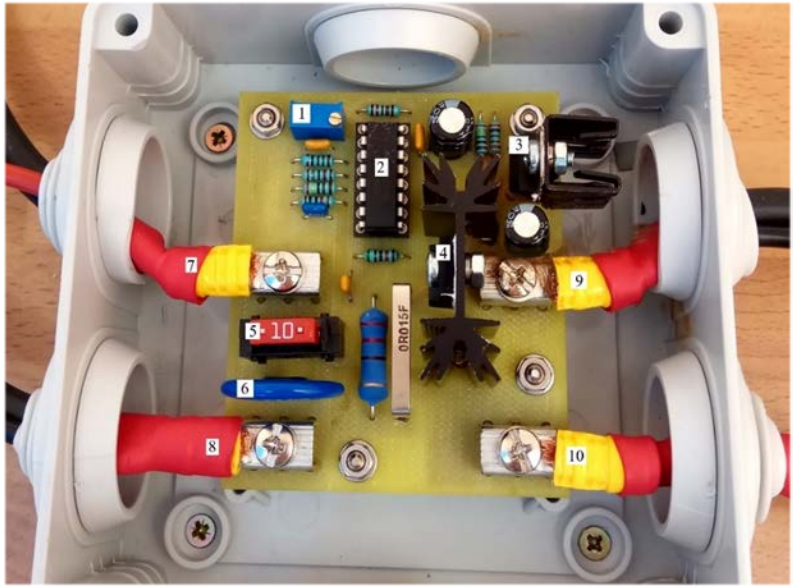


- The concept of the proximity of the constant voltage to the MPP tracking makes possible an on/off circuit that approximately maintains the **average input voltage**.
- The price to pay is a power loss. In our case 3 W are lost from a nominal of 300 W_p.
- 7×6 cm PCB using through-hole components costing ~ 5 €.

Detail of the circuit prototype implementation

Requires a minimum of 8 V nominal of PV supply (actually starts working with 8 V). It consumes 1-10 W, being worthwhile for $150\,\frac{\mathrm{W}}{\mathrm{m}^2} < G_T < 600\,\frac{\mathrm{W}}{\mathrm{m}^2}$ with an MPP matching resistance at W_p.





1. Potenciómetro de 2,2 kΩ
2. Generador de pulsos (PWM) LM3524D
3. Transistor de potencia MOSFET TK30A06N1
4. Regulador de tensión LM317
5. Fusible protector del circuito de 15 A tipo automoción
6. Varistor 33 V/20 A
7. Terminal positivo de entrada
8. Terminal negativo de entrada
9. Terminal negativo de salida
10. Terminal positivo de salida

Images by Carlos Serrano-Hernández, Master Thesis 2018 “CIRCUITO DE CONTROL DE PANEL SOLAR FOTOVOLTAICO SIN BATERÍA”

.

Modified commercial cooking pot for TES

Original electronic boiler/fryer
110-230 V 900 W. 5 liters capacity.
Walls are insulated.
Pressure cooking is possible.
Removable inner pot.

DC resistance added to the inner hot plate.
230 V AC operation is kept.

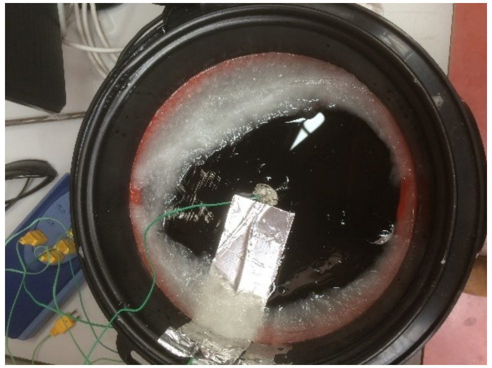
When there is need of using the grid electricity, the pot is still valid.

Inner pot with thermocouple.

Bottom of inner pot filled by a composite of PCM erythritol and aluminum tubes.

Bottom of inner pot covered and with thermocouple

Expansion problems →



PV solar cooker testing platform

PV testing platform. Comparing using batteries is possible.

Especificaciones	
Modelo	RED310-72M
Potencia máxima (Pmax)	310W
Tensión de potencia máx. (Vmp)	37,52V
Tensión de corriente máx. (Imp)	8,27A
Tensión de circuito abierto (Voc)	46,46V
Corriente de cortocircuito (Isc)	8,7A
Eficiencia de célula (%)	18.40%
Máxima tensión del sistema (V)	1000VDC
Coef. de temp Isc (%)/ºC	0,037%/ºC
Coef. de temp Voc (%)/ºC	-0,34%/ºC
Coef. de temp Pmax (%)/ºC	-0,48%/ºC
Temperatura nominal de funcionamiento de célula	45±2ºC
Tolerancia	±3%
Tipo de célula (mm)	Policristalino
Nº de células	156x156mm
Tipo de conectores	72 células
Peso (kg)	23kg
Dimensiones (mm)	1956x992x50mm

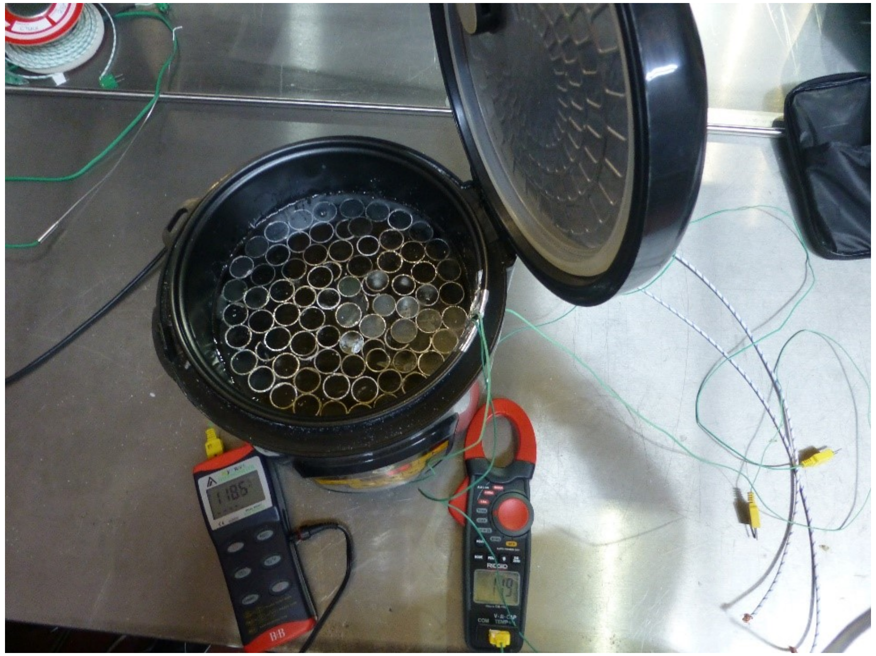
Ficha técnica testeada según STC, STC:AM 1.5,1000W/m2, 25ºC.

PV testing platform. Very simple PV controller circuit, pot and data logger.

Evaporative losses experiment.
Open pot on lower platform.

Pot modification and preliminary experiments with erythritol

Boiling experiment, no storage with DC resistance.



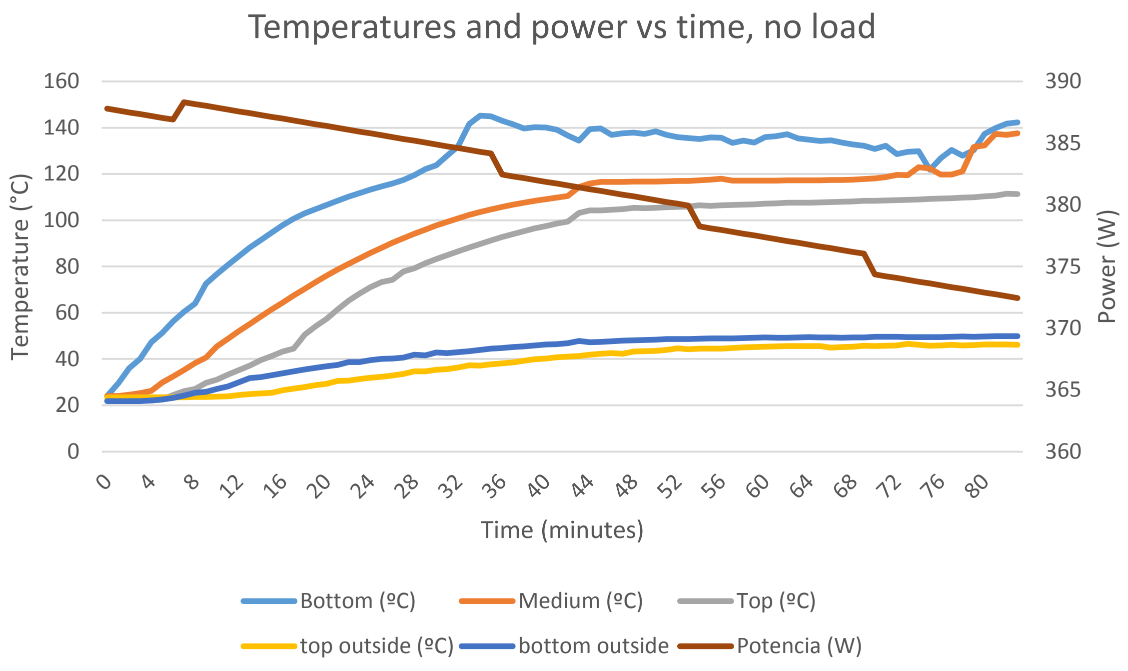
PCM composite Thermal Energy Storage (TES). Aluminum tubes directionally enhance heat conductivity. Melting before closing.

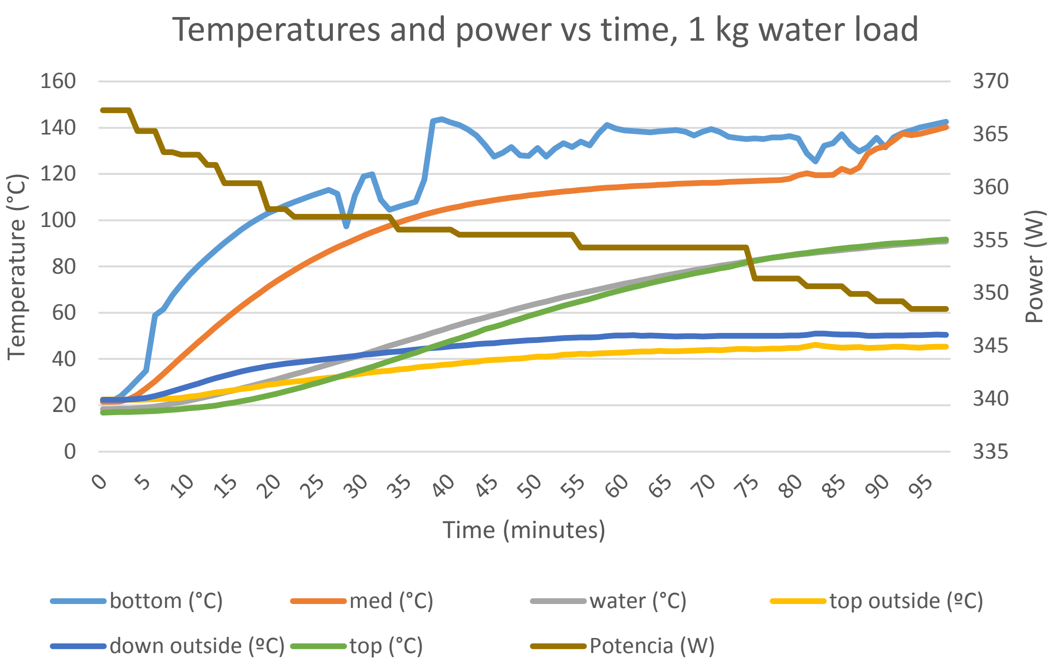
TES Closed

PCM retraction when solidifying.

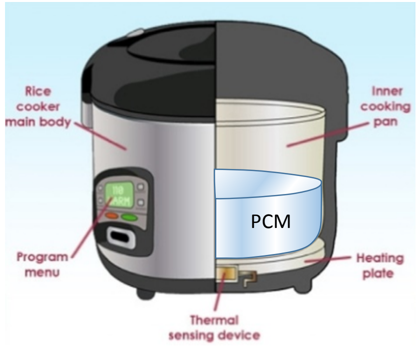
$$E_{PCM} = 3\ \text{kg} \times \frac{340\ \text{kJ}}{\text{kg}} = 0.28\ \text{kWh} \rightarrow \text{capacity to heat up to boiling point 2 kg of water}$$

Experimental results: charging, descending power

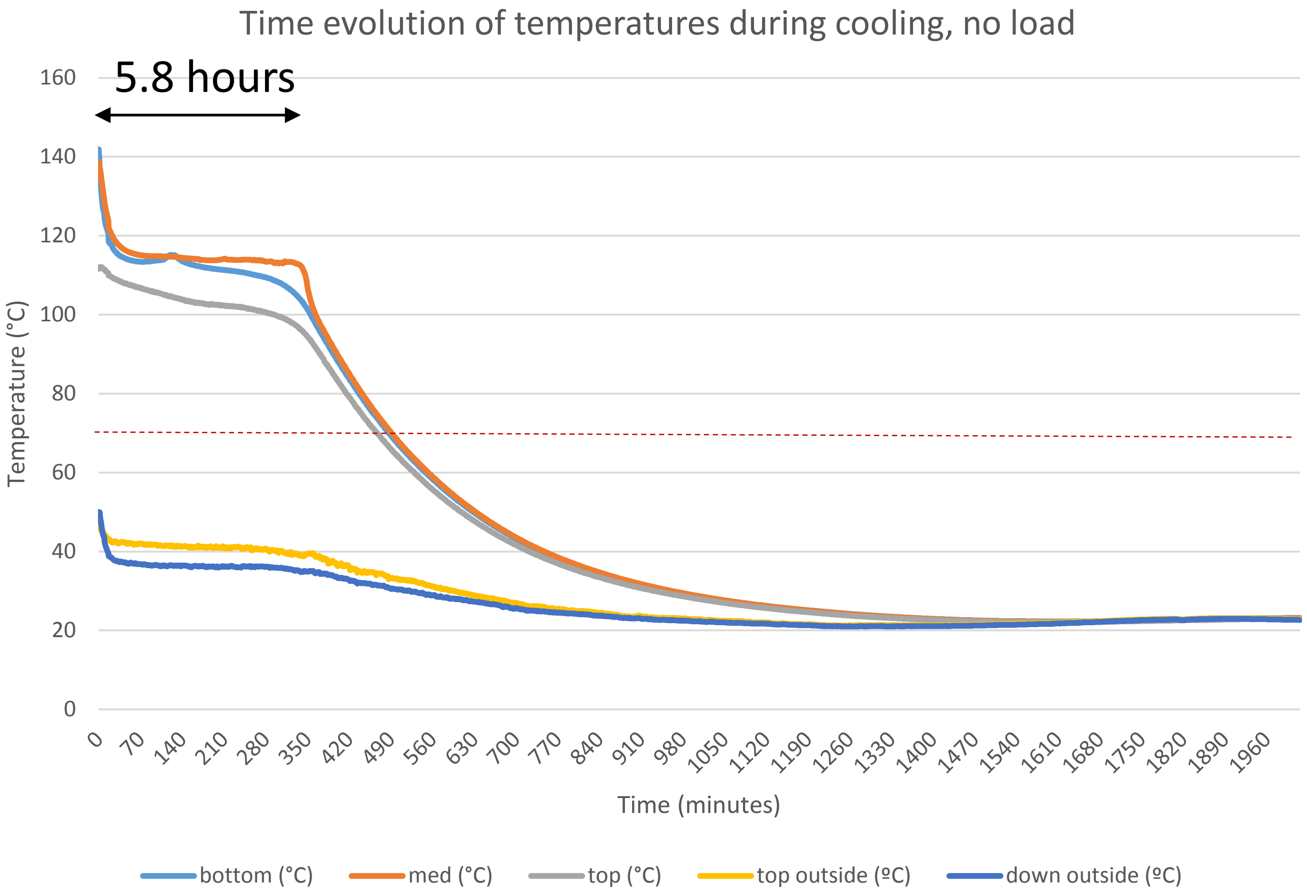


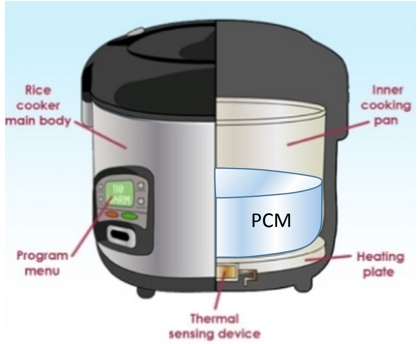


2 MJ_e = 0,6 kWh added, 83 min with no load and 97 min loaded with water. About 1 hour is necessary for full storage, no load. With load, about 1.5 hour. Differences not relevant. $\eta = 0{,}86$ and 0,80 resp.



Experimental results: cooling, no load

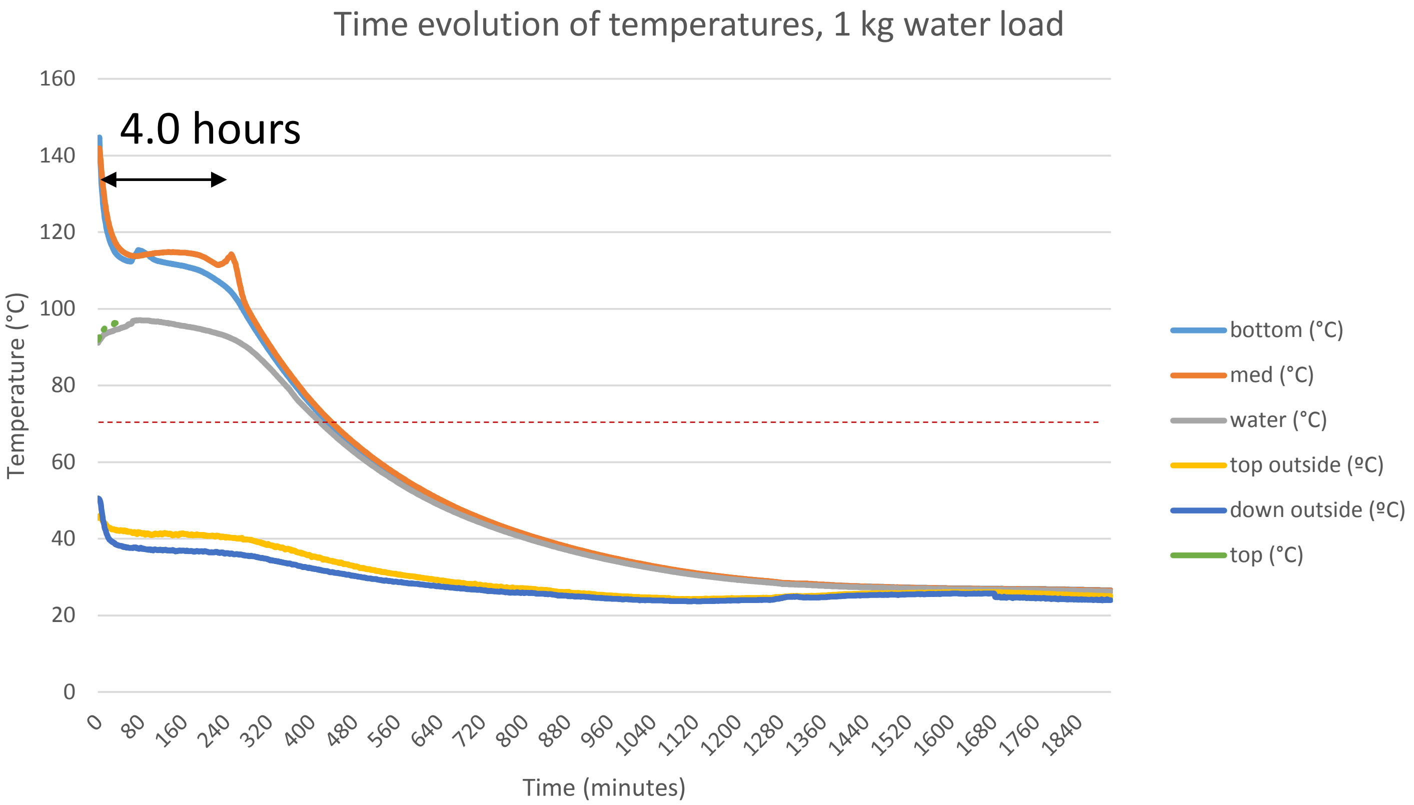


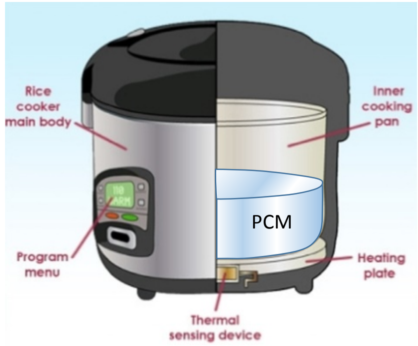


- No external insulation was added.
- About 6 hours heat is available for cooking, heating or sanitary water preparation
- Characteristic cooling time t^*_{coo} is 3.3 hours.

$$\frac{T - T_a}{T_0 - T_a} = \exp\left(-\frac{t}{t^*_{coo}}\right)$$

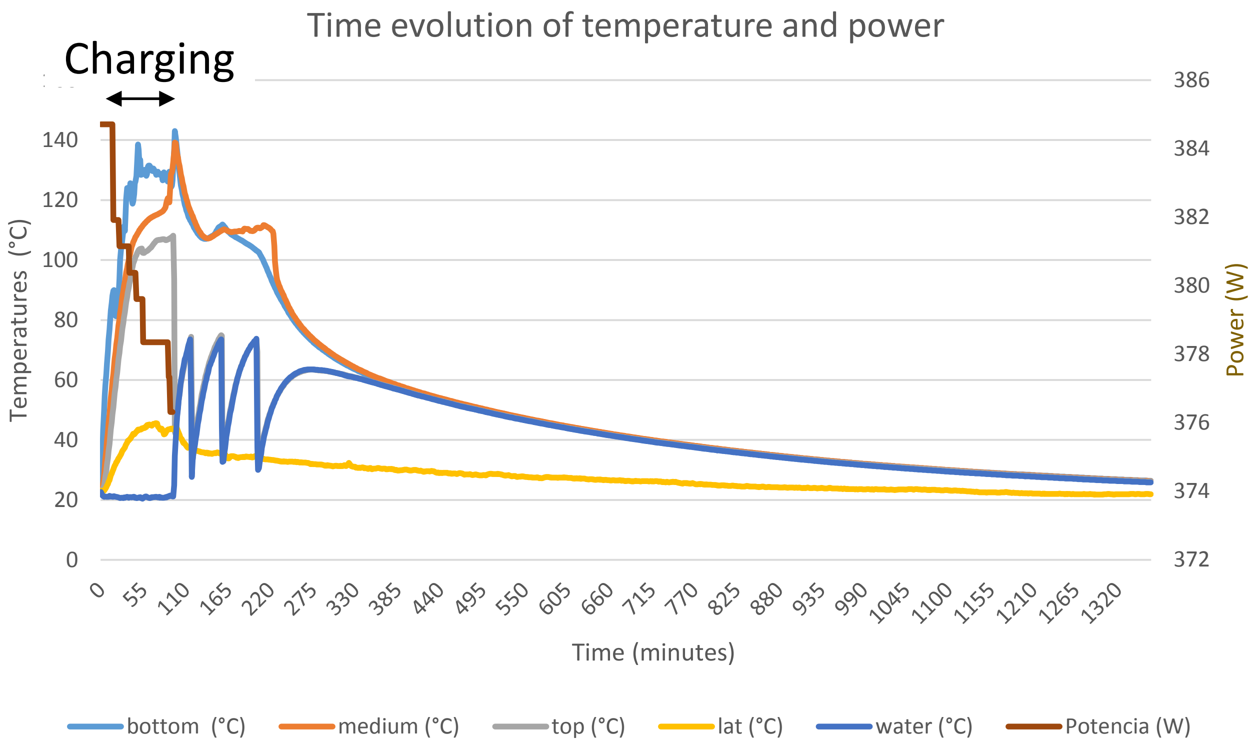
Experimental results: cooling, 1 kg water load

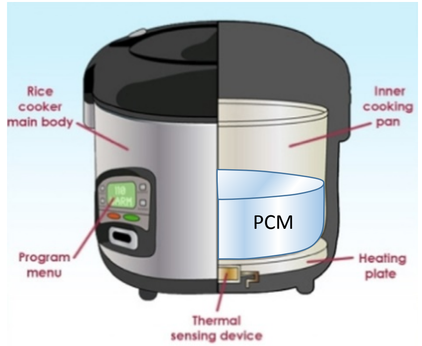




- No external insulation was added. Internally yes.
- Evaporation losses are evident in speeding of the cooling.
- About 4 hours heat is available for cooking, heating or sanitary water preparation
- Characteristic cooling time is 3.3 hours.

Experimental results: cooking capacity

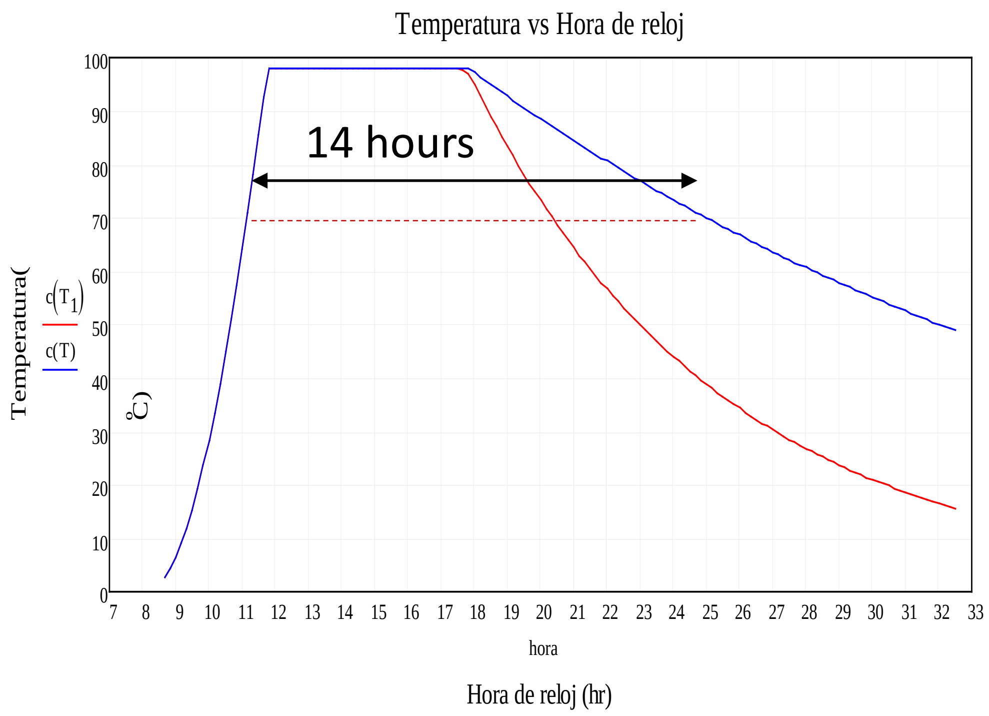




After charging with no load:

- Up to 3 loads of 1 kg can be brought up to 74 ºC in about 25 minutes average.
- 4th load heats up to 63 ºC. And keeps warm for 8 hours.

Modeling results: effect of a “hay basket”



Even with no PCM:

- The retention time can be extended overnight.

Conclusions

For the developing countries families, PV cooking:

- Is possible at reasonable investments, if micro-financing tools are deployed.
- It will highly improve the living level and allows sustainable development.
- The “high” power needed for cooking ($\sim 300\ \mathrm{W_p}$) will allow:
  - A quantum leap from primitive into “electric energy” world.
  - Future integration into smart grids.
- First-stage electrification for remote communities.
- The design proposed:
  - Uses low-cost commercial components and a appropriate technology circuit.
  - **Substitutes batteries by thermal storage (TES) using an edible low-cost PCM.**

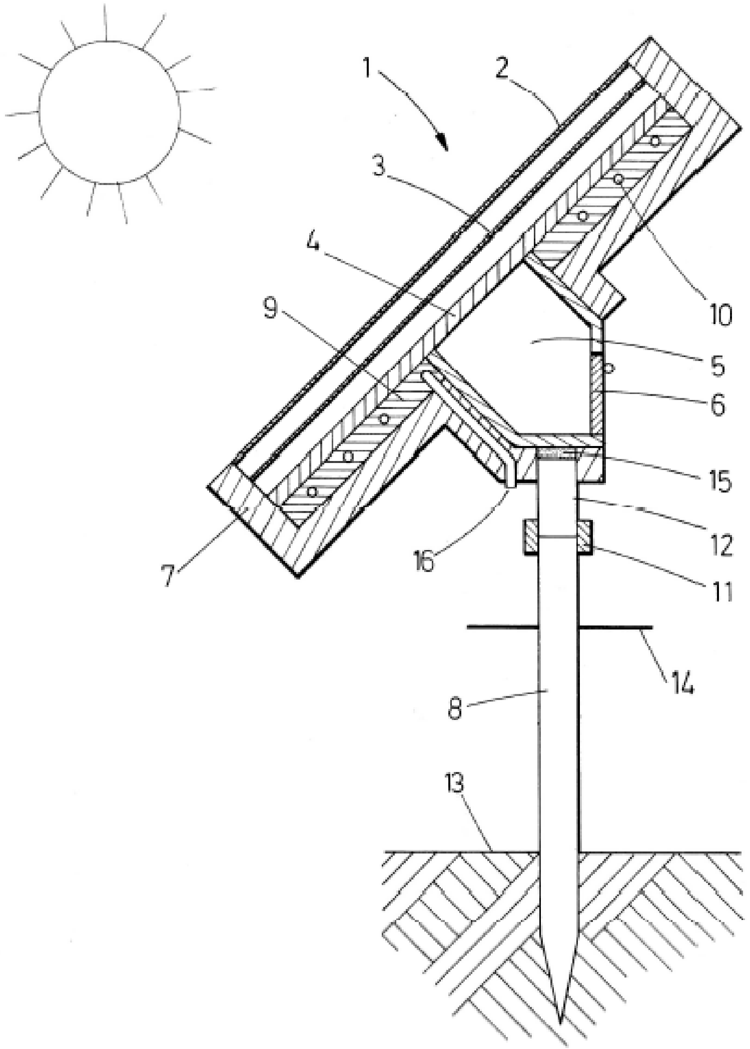
Solar cooker as a urban furniture

Requerimientos:

- Permanentemente al exterior
- Sin mantenimiento
- Sin consumo ninguno
- Anti-vandálico
- Seguro, especialmente para niños
- Sencilla de usar e inmediata
- Proyecta sombra a los usuarios

Diseño:

- Horno solar
- Almacenamiento en placa metálica
- Patente



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

Solar cooker as a urban furniture

Siempre está caliente, aunque hay que orientarla al sol a mano. Puede producir agua caliente para lavado.

Solar cooker as a urban furniture. Modeling

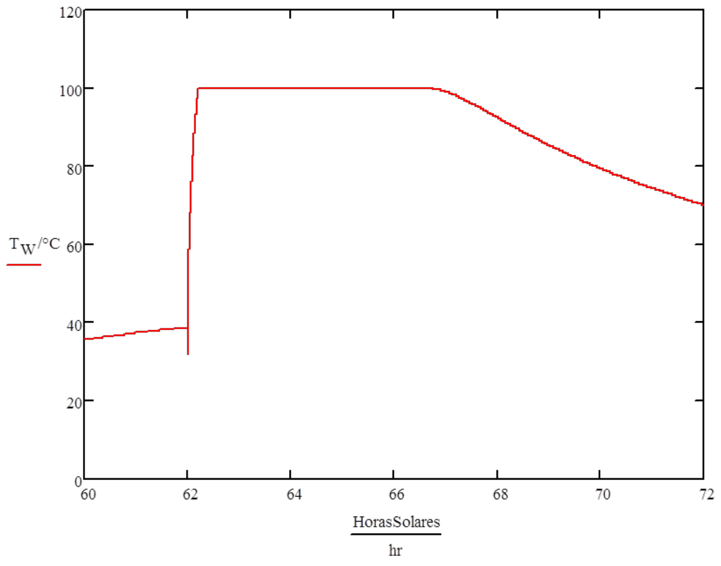
Clear day tests

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

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

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

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



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

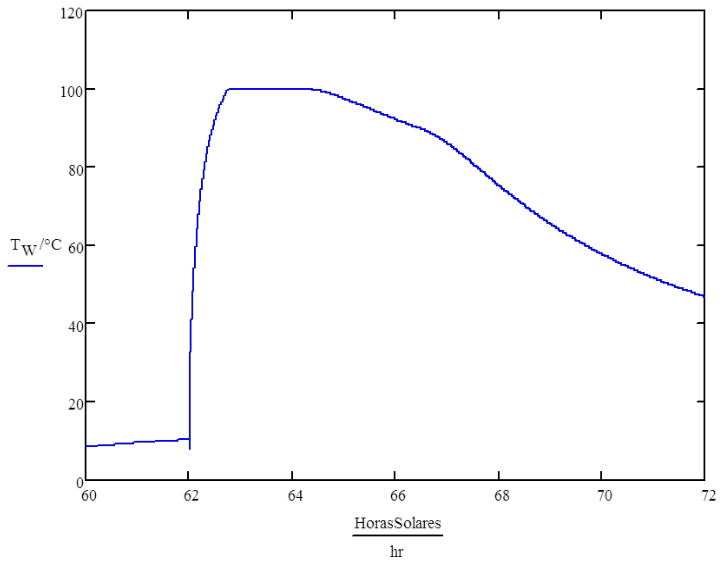
$t_{eb} = 31$ min at 17:30 pm, solar time

June, Madrid

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

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

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

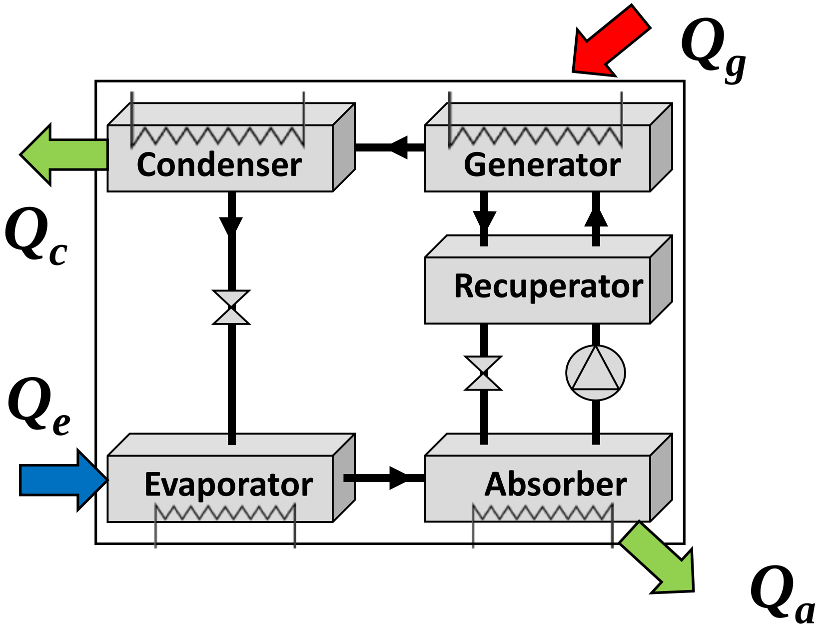


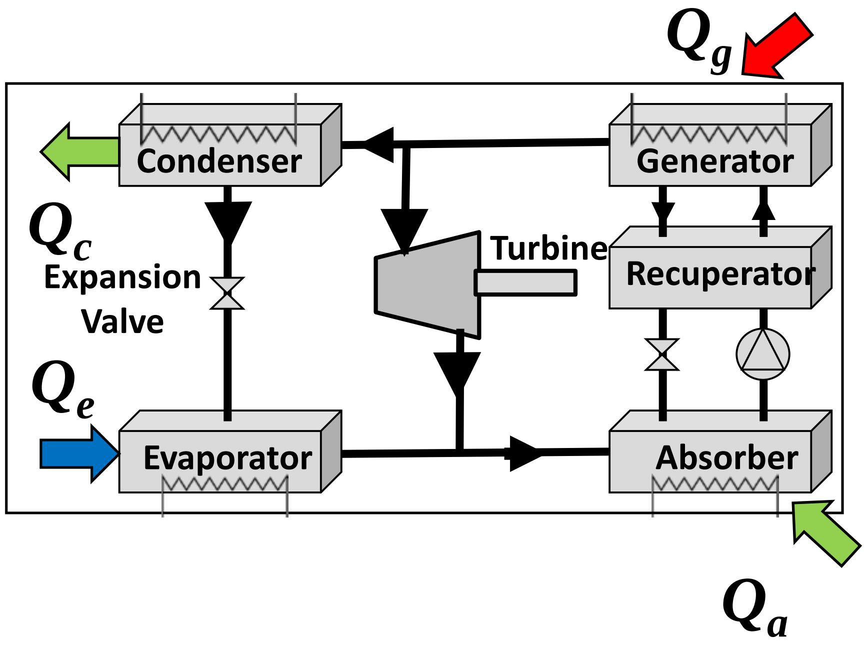
$t_{eb} = 46$ min at 14:00 pm, solar time

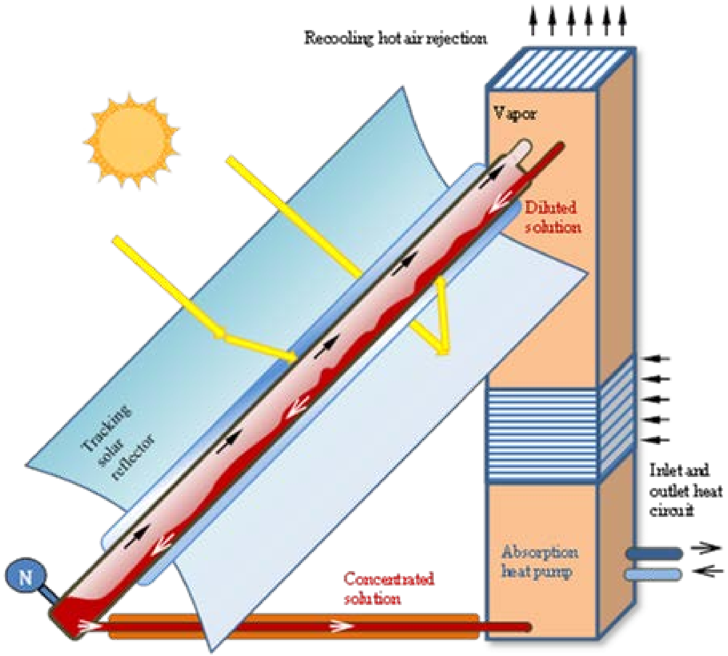
January, Madrid

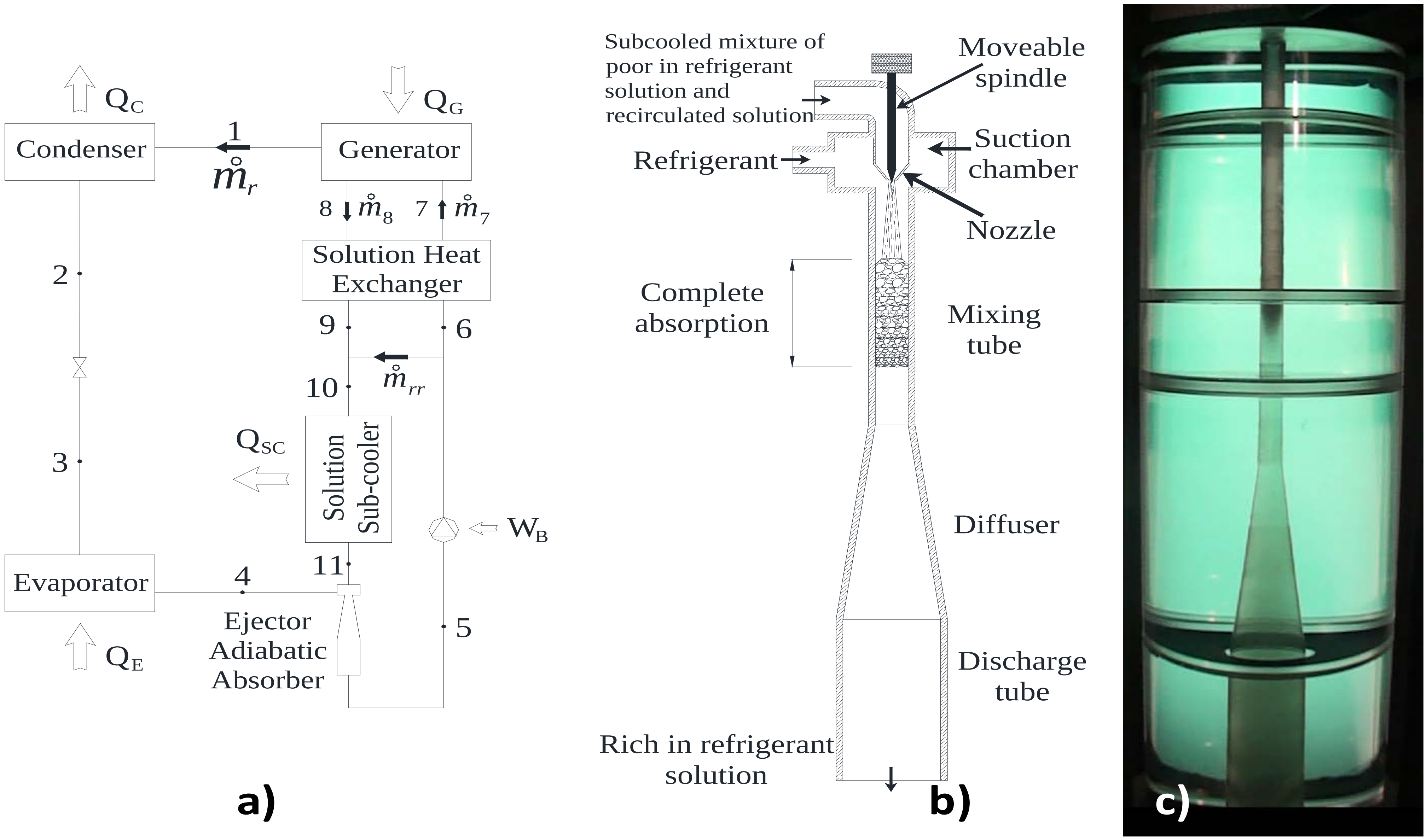
Research activity of the group "ITEA" in the field of absorption technology

- Hybrid cycles capable of producing cold/heat/electricity.
- Combined cycles capable of consuming waste/solar heat or electricity.
- Solar energy by direct production of refrigerant inside the collector.


Q_g
Condenser
Generator
Q_c
Recuperator
Q_e
Evaporator
Absorber
Q_a


Q_g
Condenser
Generator
Q_c
Turbine
Expansion
Valve
Recuperator
Q_e
Evaporator
Absorber
Q_a


Recooling hot air rejection
Vapor
Diluted solution
Tracking solar reflector
Inlet and outlet heat circuit
Absorption heat pump
Concentrated solution
N


Q_C
Q_G
Condenser
1
$\mathring{m}_r$
Generator
8 $\mathring{m}_8$
7 $\mathring{m}_7$
Solution Heat Exchanger
2
9
6
$\mathring{m}_{rr}$
10
Q_{SC}
Solution Sub-cooler
3
W_B
Evaporator
11
4
Ejector Adiabatic Absorber
5
Q_E
a)
Subcooled mixture of poor in refrigerant solution and recirculated solution
Moveable spindle
Refrigerant
Suction chamber
Nozzle
Complete absorption
Mixing tube
Diffuser
Discharge tube
Rich in refrigerant solution
b)
c)

Thank your very much for the attention

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- Miriam Cabañas

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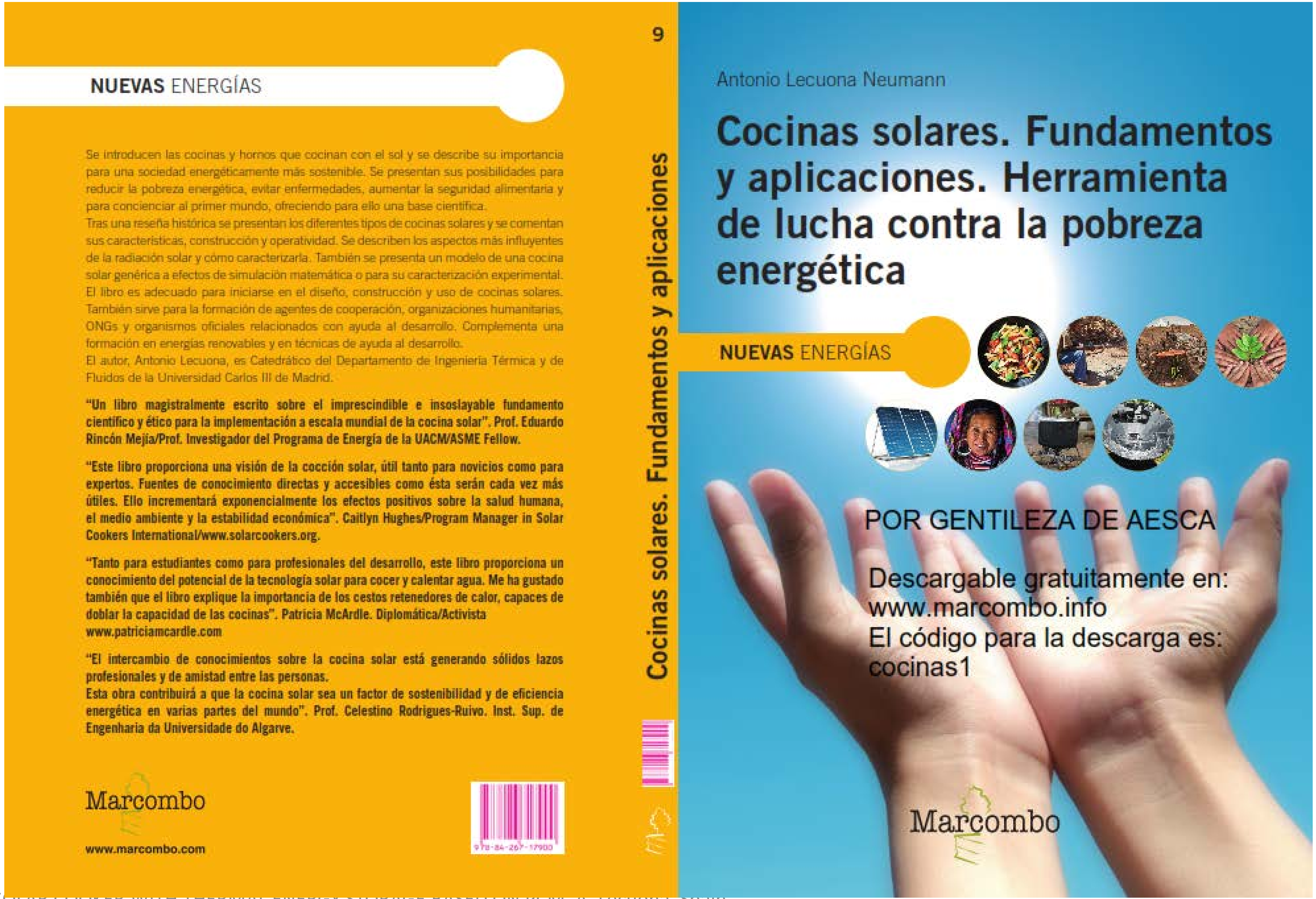
- Jorge Picurelli
- Manuel Santos
- David Díaz
- Israel Pina



NUEVAS ENERGÍAS

Se introducen las cocinas y hornos que cocinan con el sol y se describe su importancia para una sociedad energéticamente más sostenible. Se presentan sus posibilidades para reducir la pobreza energética, evitar enfermedades, aumentar la seguridad alimentaria y para concienciar al primer mundo, ofreciendo para ello una base científica.
Tras una reseña histórica se presentan los diferentes tipos de cocinas solares y se comentan sus características, construcción y operatividad. Se describen los aspectos más influyentes de la radiación solar y cómo caracterizarla. También se presenta un modelo de una cocina solar genérica a efectos de simulación matemática o para su caracterización experimental.
El libro es adecuado para iniciarse en el diseño, construcción y uso de cocinas solares. También sirve para la formación de agentes de cooperación, organizaciones humanitarias, ONGs y organismos oficiales relacionados con ayuda al desarrollo. Complementa una formación en energías renovables y en técnicas de ayuda al desarrollo.
El autor, Antonio Lecuona, es Catedrático del Departamento de Ingeniería Térmica y de Fluidos de la Universidad Carlos III de Madrid.

"Un libro magistralmente escrito sobre el imprescindible e insoslayable fundamento científico y ético para la implementación a escala mundial de la cocina solar". Prof. Eduardo Rincón Mejía/Prof. Investigador del Programa de Energía de la UACM/ASME Fellow.

"Este libro proporciona una visión de la cocción solar, útil tanto para novicios como para expertos. Fuentes de conocimiento directas y accesibles como ésta serán cada vez más útiles. Ello incrementará exponencialmente los efectos positivos sobre la salud humana, el medio ambiente y la estabilidad económica". Caitlyn Hughes/Program Manager in Solar Cookers International/www.solarcookers.org.

"Tanto para estudiantes como para profesionales del desarrollo, este libro proporciona un conocimiento del potencial de la tecnología solar para cocer y calentar agua. Me ha gustado también que el libro explique la importancia de los cestos retenedores de calor, capaces de doblar la capacidad de las cocinas". Patricia McArdle. Diplomática/Activista www.patriciamcardle.com

**"El intercambio de conocimientos sobre la cocina solar está generando sólidos lazos profesionales y de amistad entre las personas.
Esta obra contribuirá a que la cocina solar sea un factor de sostenibilidad y de eficiencia energética en varias partes del mundo". Prof. Celestino Rodrigues-Ruivo. Inst. Sup. de Engenharia da Universidade do Algarve.**

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9

Cocinas solares. Fundamentos y aplicaciones

Antonio Lecuona Neumann

Cocinas solares. Fundamentos y aplicaciones. Herramienta de lucha contra la pobreza energética

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