Presented at the COMSOL Conference 2009 Milan



# Simulation of the Convective Heat Transfer and Working Temperature Field of a Photovoltaic Module using COMSOL Multiphysics

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# Introduction

- A great portion of the solar radiation absorbed by a photovoltaic module (typically 85% of the incident radiation) **is not converted into electrical energy**.

- It is wasted by the **increase** of the module's temperature, **reducing its efficiency** by heat transfer with the surrounding medium.

- The working temperature of photovoltaic modules **depends on different environmental factors**:

  - The ambient temperature.
  - The solar irradiation.
  - The relative humidity.
  - The direction and speed of the wind.
  - The construction materials.
  - The installation of the module.

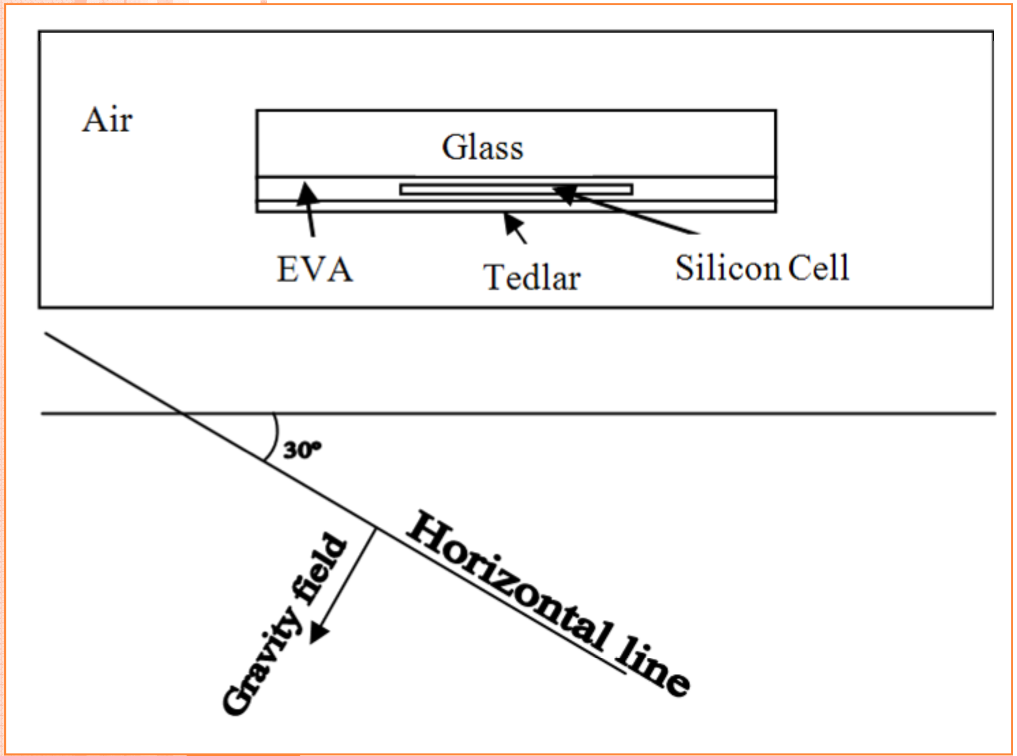
**PRESENT WORK**: We perform a **numerical study, using COMSOL Multiphysics**, of the convective heat transfer and working temperature field of a photovoltaic module.

For ease, we have chosen a very simple module with a unique Si cell.

# GEOMETRY

# Geometry

- We suppose that the module is installed forming 30º with the horizontal axis.
- A schematic of the simulation system is




- For clarity, the distances are not in scale.
- All the thermal and fluid parameters of the materials involved have been found in the literature.

## Solid Subdomains

1. The glass of the cover. Width: 250 mm. Thickness: 3 mm.
2. The Silicon cell. Width: 125 mm. Thickness: 0.4 mm.
3. The EVA (ethylene vinyl acetate) film. Width: 250 mm. Thickness: 0.8 mm.
4. The Tedlar back film. Width: 250 mm. Thickness: 0.05 mm. White reflective color.

## Gaseous Subdomain

5. The air that surrounds the module. Width: 37 cm. Height: 14 cm.

# Thermal equations

- We use the **General Heat Transfer** application mode.

- **GASEOUS SUBDOMAIN:** Heat conduction and convection,

$$\vec{\nabla}(-k\vec{\nabla}T) = Q - \rho c_p \vec{u} \cdot \vec{\nabla}T$$

- The velocity field is coupled with the Navier-Stokes equations (see below) that are treated in the Weakly Compressible Navier-Stokes application mode.

- The density and thermal conductivity of the air are related with the temperature

$$\rho = 1.013 \cdot 10^5 \frac{28.8 \cdot 10^{-3}}{8.314T} \qquad k = 10^{-3.723+0.865 \log T}$$

- **SOLID SUBDOMAINS:** Only heat conduction,

$$\vec{\nabla}(-k\vec{\nabla}T) = Q$$

- *Q* is zero for the Tedlar, glass and EVA subdomain

- *Q* has a value of 1.005 MW/m$^3$ for the silicon cell subdomain, which corresponds to an incident irradiation of 1000 W/m$^2$ homogeneously distributed minus a 15 % efficiency of electrical conversion.

# FLUID EQUATIONS

- The fluid equations are only applicable in the gaseous subdomain (air).

- They are the corresponding to the **Weakly Compressible Navier-Stokes** application mode.

$$\rho\vec{u}\cdot\vec{\nabla}\vec{u} = \vec{\nabla}\left[-p\mathbf{I} + \eta\left(\vec{\nabla}\vec{u} + (\vec{\nabla}\vec{u})^{\mathrm{T}}\right) - \frac{2}{3}\eta(\vec{\nabla}\cdot\vec{u})\mathbf{I}\right] + \vec{F}$$

$$\vec{\nabla}\cdot(\rho\vec{u}) = 0$$

- The air viscosity is related with the temperature: $\eta = 6\cdot 10^{-6} + 4\cdot 10^{-8}T$

- The **body force** acting on the fluid is the buoyancy force due to the **dependence of the density of the air with the temperature**.

$$\rho = 1.013\cdot 10^{5}\,\frac{28.8\cdot 10^{-3}}{8.314T}$$

- In the case of the present geometry:

$$\vec{F} = \frac{1}{2}g(\rho_0 - \rho)(\hat{i} + \sqrt{3}\hat{j})$$

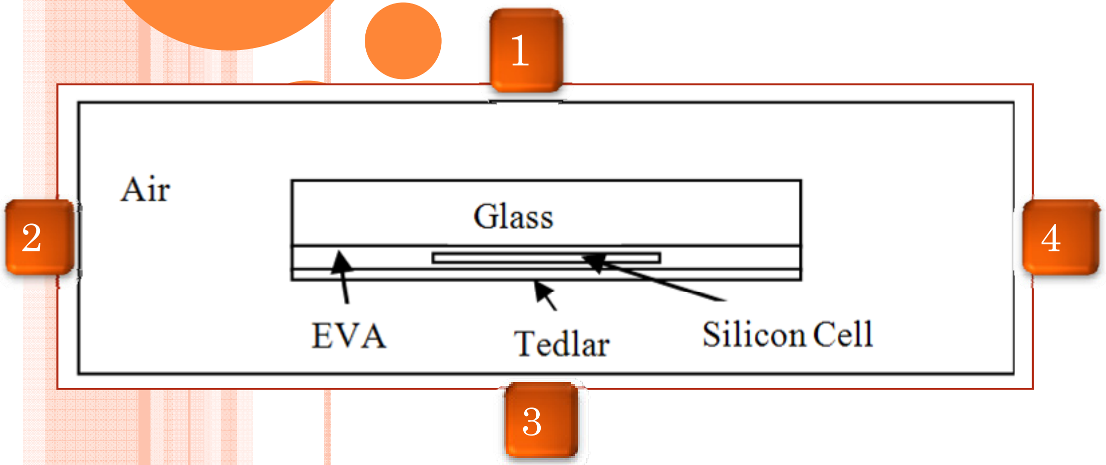
# Boundary conditions

## Boundaries 1 and 2

Weakly Compressible Navier-Stokes:
"Inlet" → "Velocity", $v_{ini}$ is the inlet wind speed

$$u_0 = v_{ini} \cos\left(\frac{\pi}{3}\right) = \frac{v_{ini}}{2} \qquad v_0 = -v_{ini} \sin\left(\frac{\pi}{3}\right) = -\frac{\sqrt{3}v_{ini}}{2}$$

General Heat Transfer: "Temperature" → 300 K, the ambient temperature.




## Boundaries 3 and 4

Weakly Compressible Navier-Stokes: "Stress" → "Normal Stress".

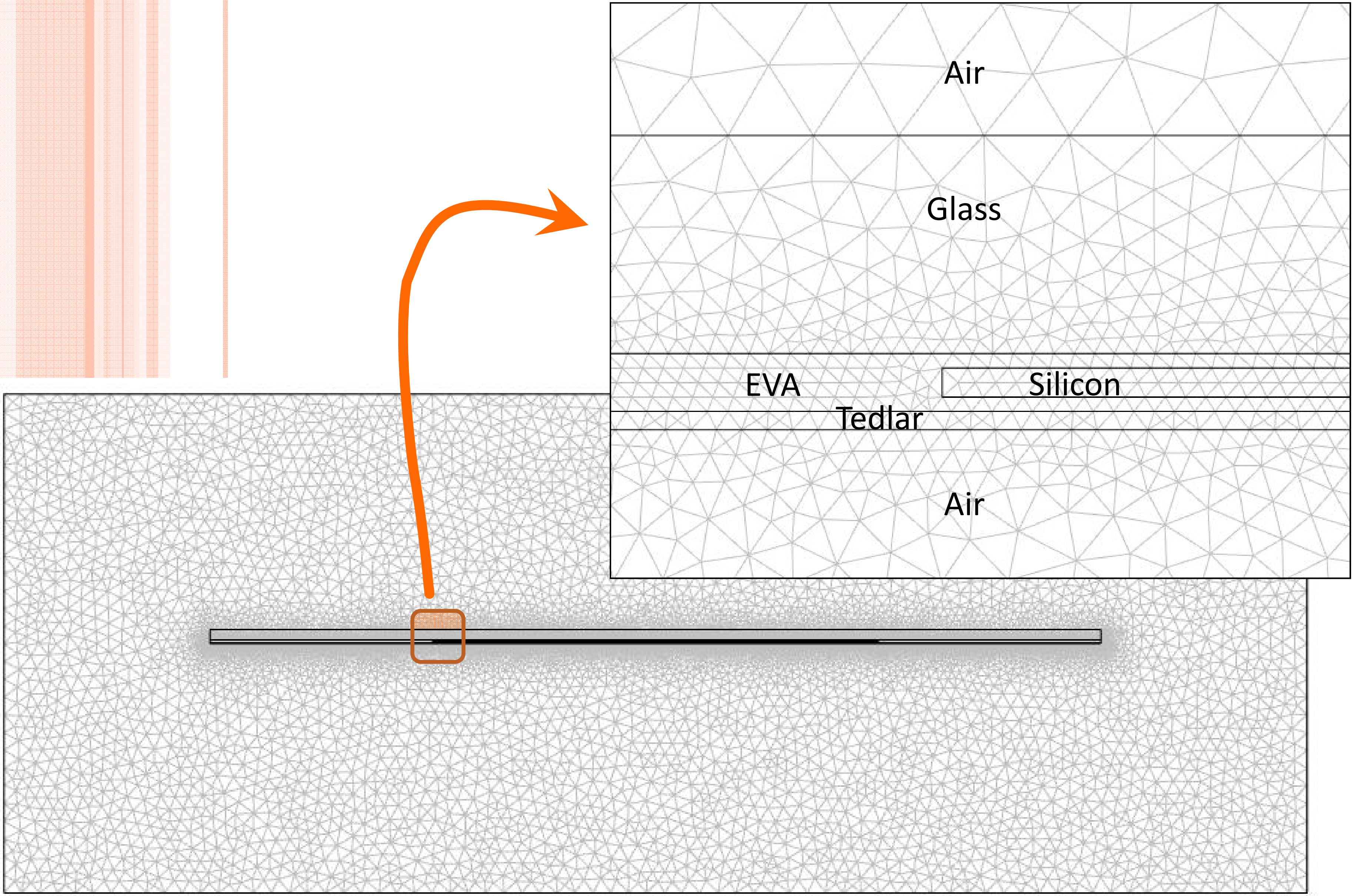
General Heat Transfer: "Convective Flux". With these conditions we try to model an unbounded domain.

## Inner boundaries

Weakly Compressible Navier-Stokes: "Wall" → "No Slip".

General Heat Transfer: "Continuity".

# MESH



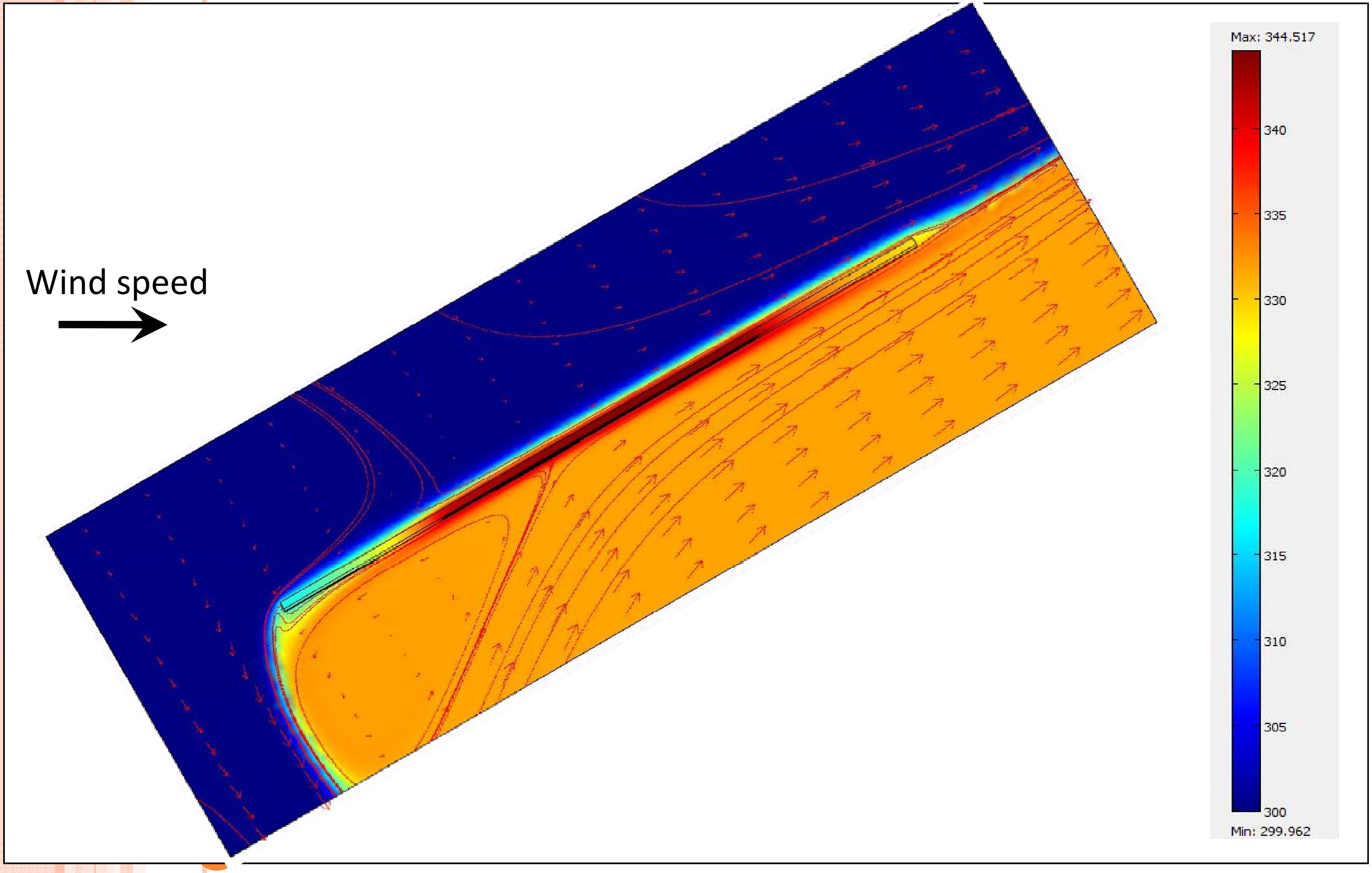
# RESOLUTION

- The problem seems to be highly non-linear.
- A **direct resolution** of the problem in a single step **was found to be impossible**.

**We performed a parametric resolution:**

- We select the **air viscosity as a varying parameter** and the first iteration was made with a viscosity value one hundred times greater than the real one.
- For a high viscosity fluid, the flow is laminar and the problem is much easier to solve.
- The fluid viscosity value is then diminished in ten steps **until it reaches the real air viscosity value at the final iteration**.

# Results




Temperature and velocity fields under a low wind speed of 0.01 m/s.
Color surface plot: temperature. Arrows and streamlines: velocity field.

# RESULTS

The wind comes from the upper and left boundaries.

From this plot, we can observe some features:

- The temperature of the module at its centre **is about 40 ºC higher than the ambient temperature**.
- **The temperature difference** from the upper and lower borders of the module is about 10 ºC.
- **There is an air vortex,** with roughly 8 cm diameter, behind the module.

The results about the temperature of the module agree well with the values founded in experiments.

# Conclusions

- We have shown the **utilization of COMSOL Multiphysics** in the thermal simulation of a working photovoltaic module.
- The **convention cooling by air is a difficult problem to solve**, but using the parametric solver we can obtain reliable solutions.
- From the numerical results, **we can extract a lot of information** about the temperature fields and heat transfer with the ambient medium.
- In particular, this procedure **could be applied in the determination of the convective heat coefficients of photovoltaic modules** made with different technologies, under several installation conditions and wind speeds.
- This will be a future work.

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# Acknowledgements

- Financial support for this work by **Junta de Andalucía, Spain**, Project P07-RNM-02504, co-financed with FEDER funds by the European Union, and photovoltaic modules manufacturer **Isofotón**, contract number 8.06/5.57.2619-1, are gratefully acknowledged.

# Thank you very much for your attention!

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