Heat Transfer and Working Temperature Field of a Photovoltaic Panel under Realistic Environmental Conditions

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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 heat transfer with the surrounding medium, and also the **increase** of the module's temperature **reduce its efficiency**.

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

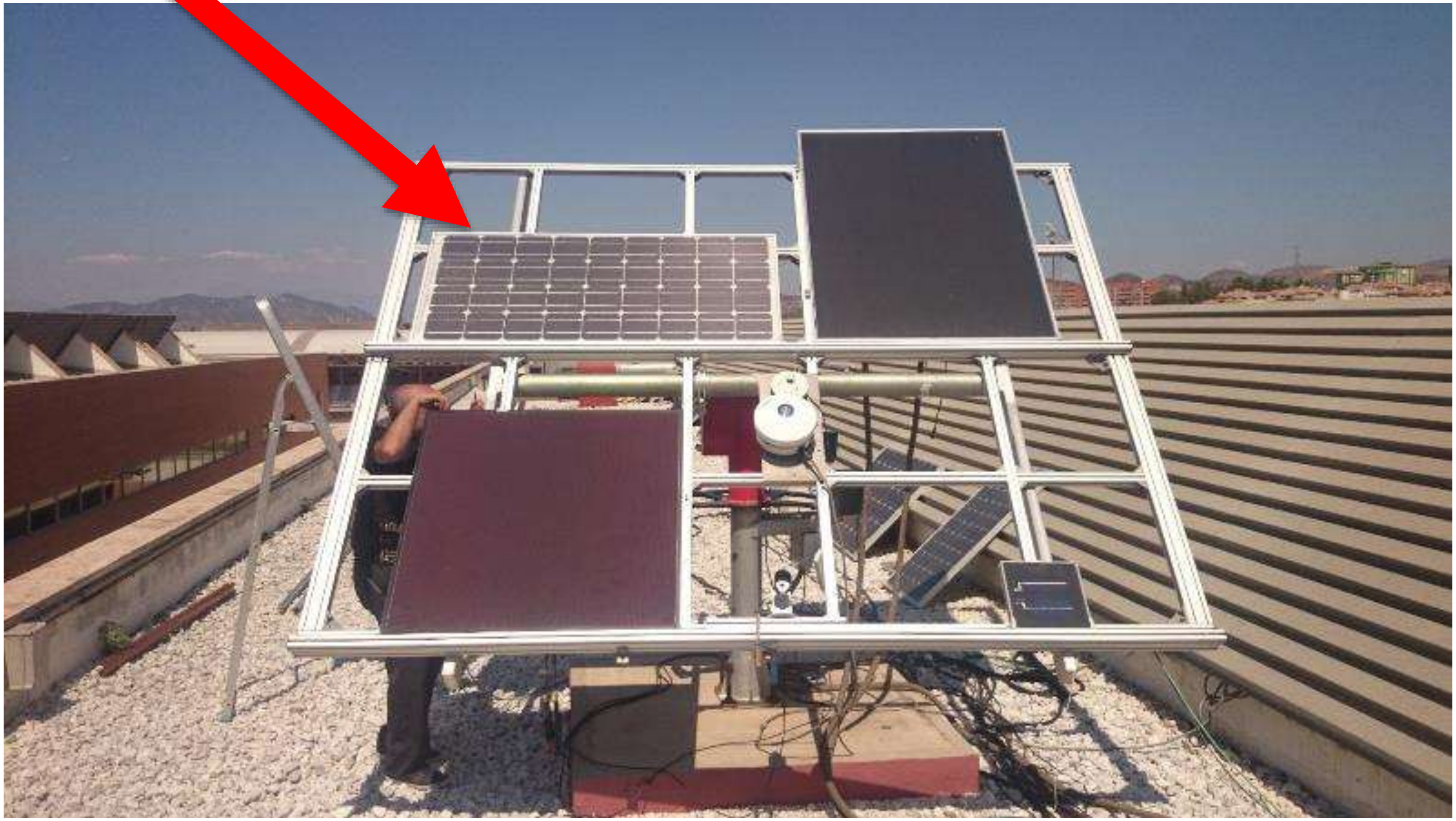
  - **The ambient temperature.**
  - **The solar irradiation.**
  - **The relative humidity.**
  - **The direction and speed of the wind.**
  - **The construction materials.**
  - **The installation of the module.**

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

Experimental system

- The PV panel is mounted in a sun tracker, so we assume normal incident direct radiation.
- Also, we have to take into account the diffuse radiation.

This one!



Experimental system

❑ The module is installed with an angle 30º with the horizontal axis.

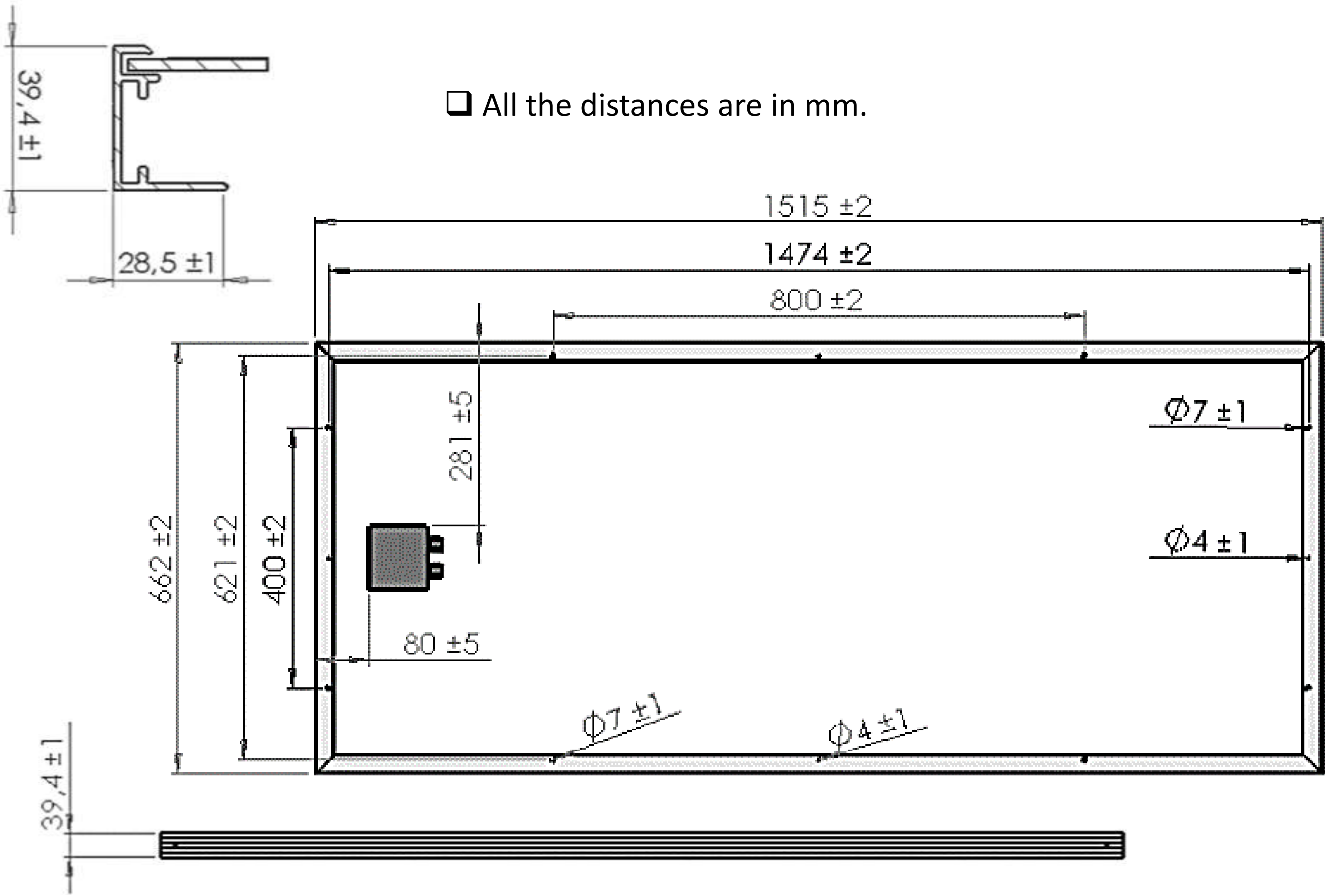
Solid parts

1. **The glass of the cover. Thickness: 3 mm.**
2. **The Silicon cells. Thickness: 0.4 mm.**
3. **The EVA (ethylene vinyl acetate) film. Thickness: 0.8 mm.**
4. **The Tedlar back film. Thickness: 0.05 mm. White re**

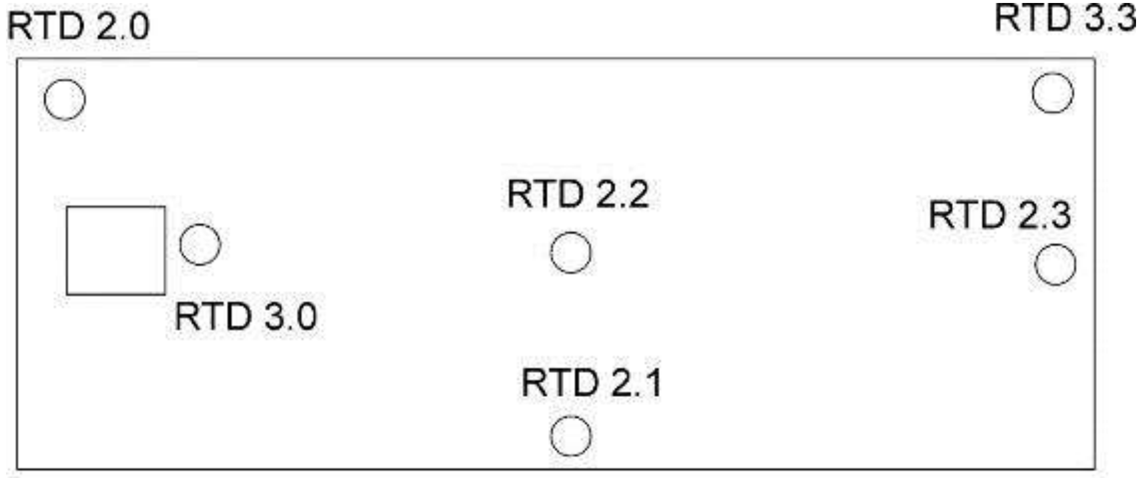
5. The aluminium frame of the PV panel.

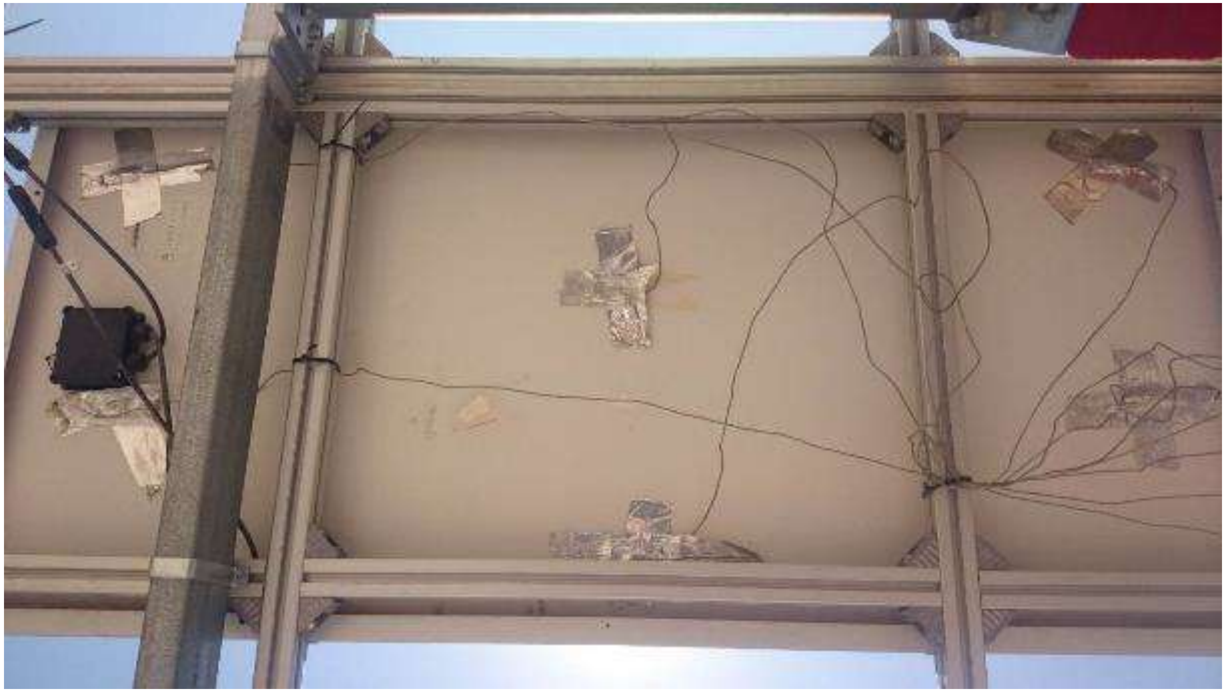
Experimental system

- All the distances are in mm.

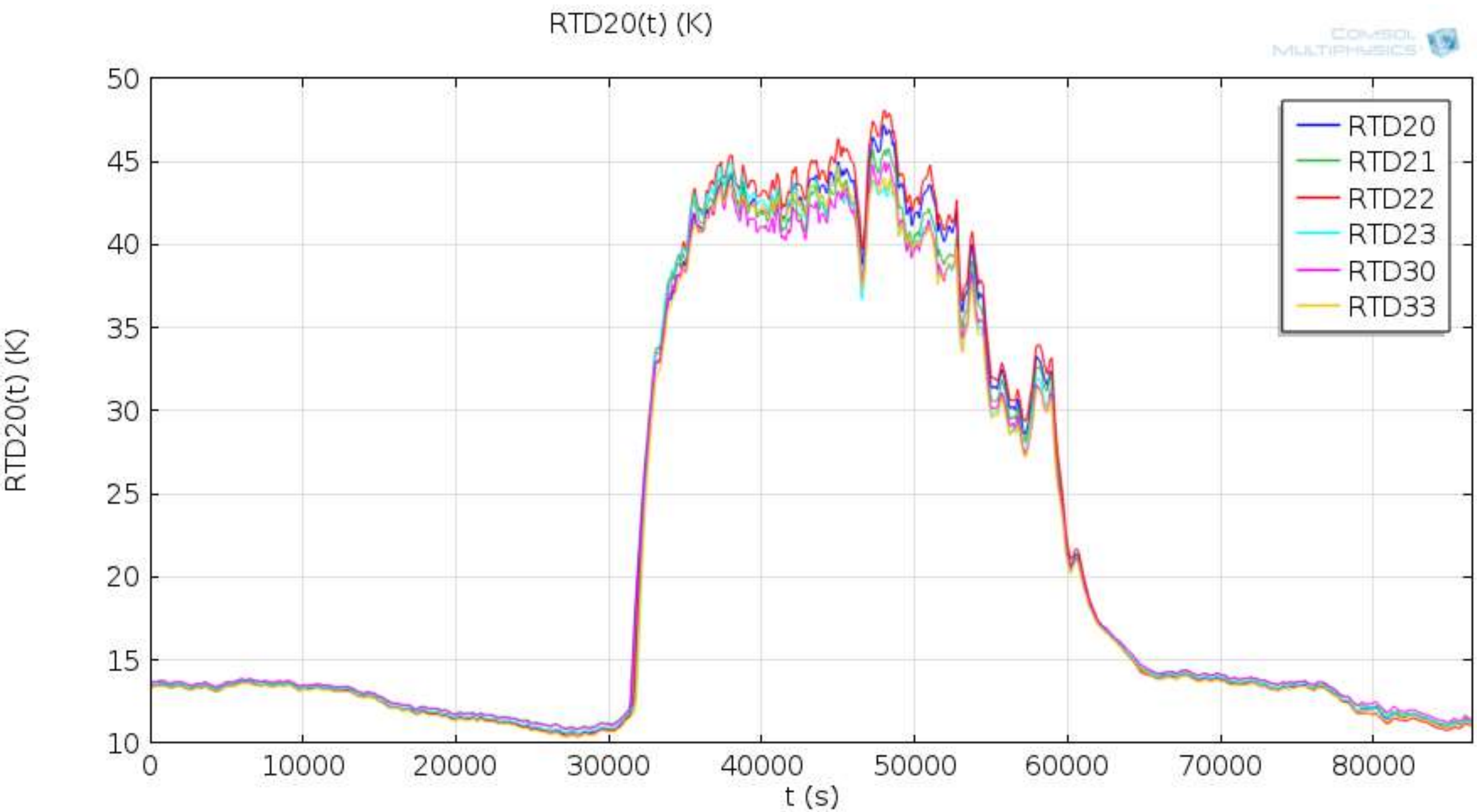


Pt100 Temperature sensors





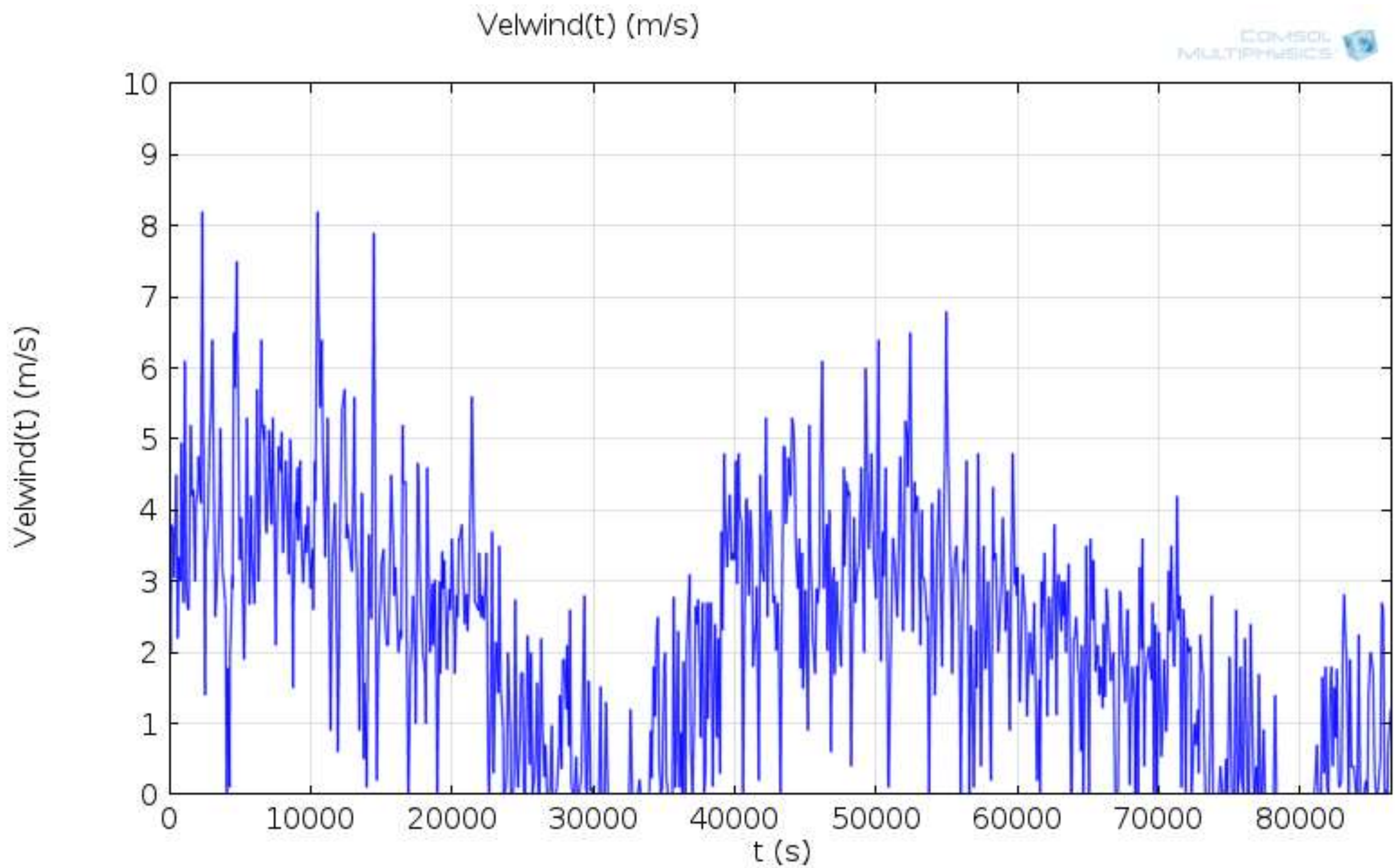
Pt100 Temperature sensors



Irradiation and meteorological measurements

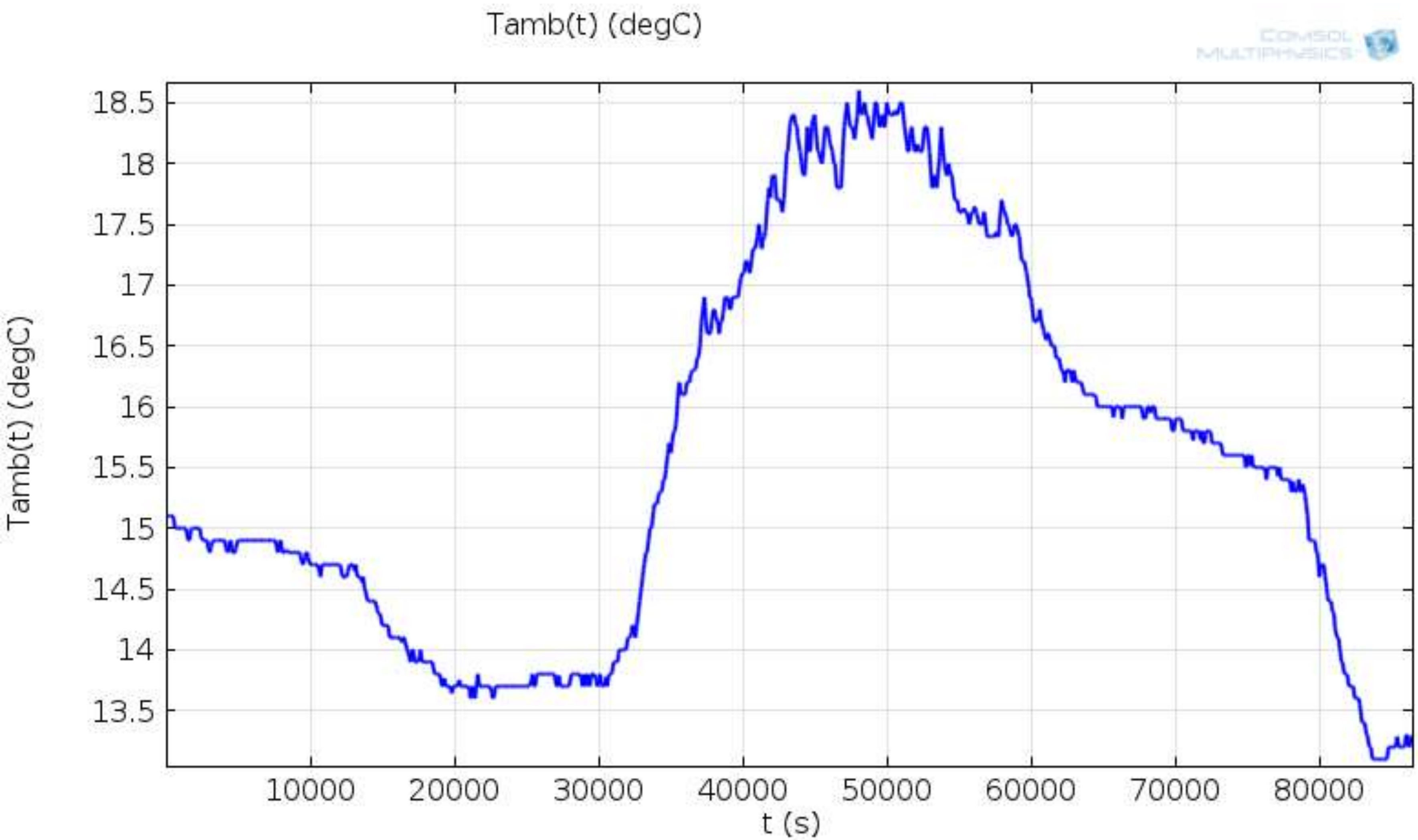
- Pyranometers, anemometer and wind vane.

Irradiation and meteorological measurements

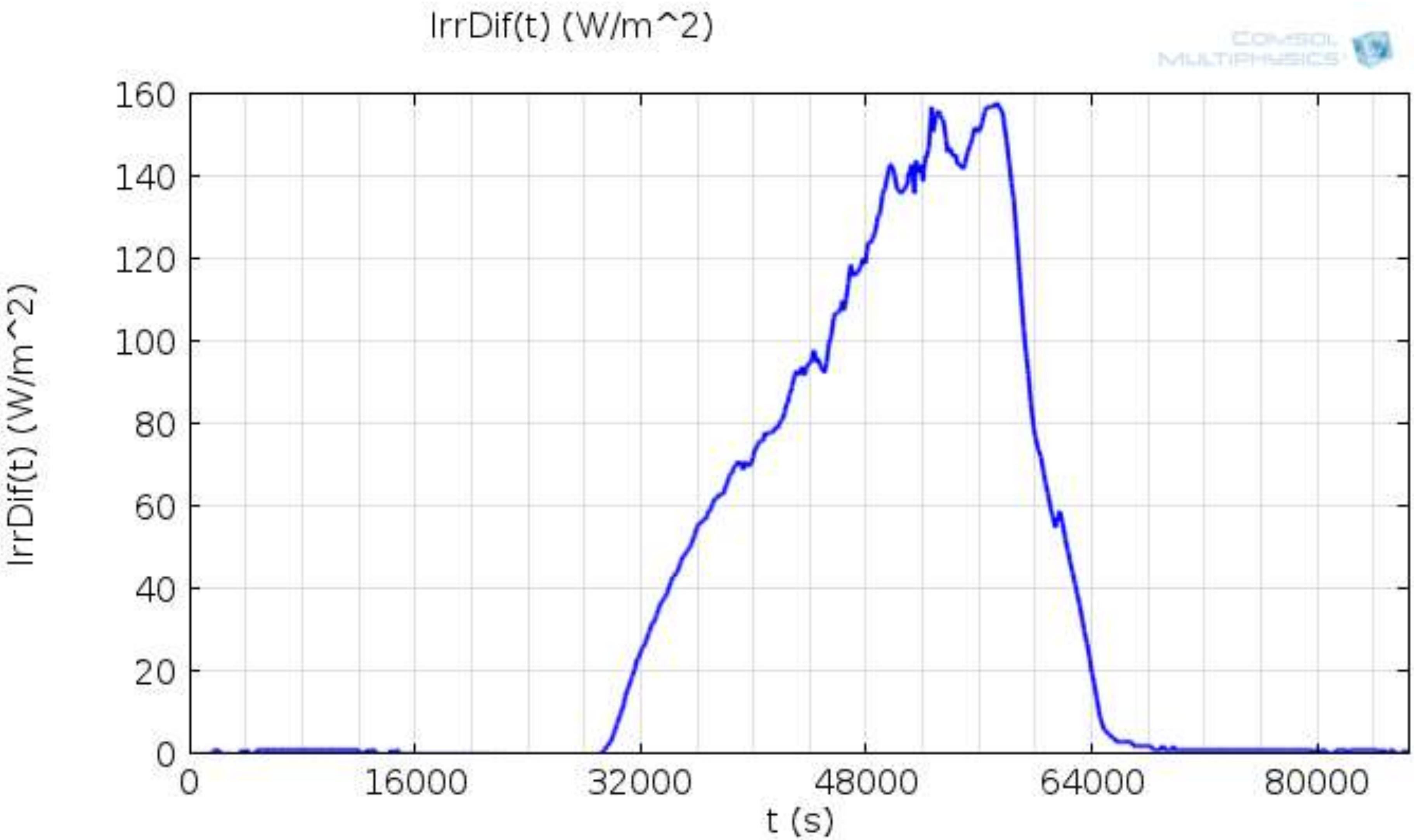


❑ The full day time-averaged wind speed is 2.19 m/s.

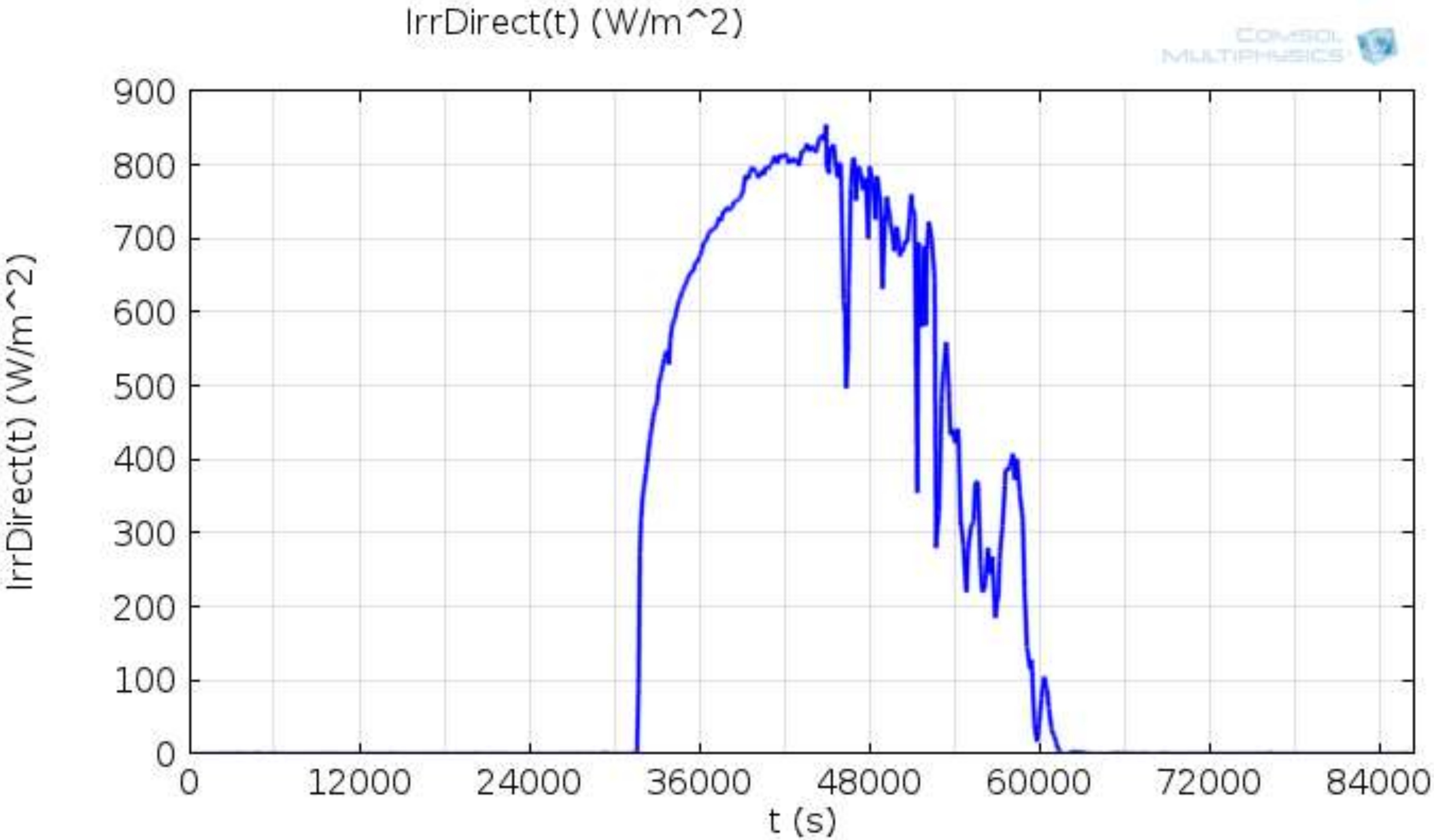
10 Irradiation and meteorological measurements



11 Irradiation and meteorological measurements



12 Irradiation and meteorological measurements

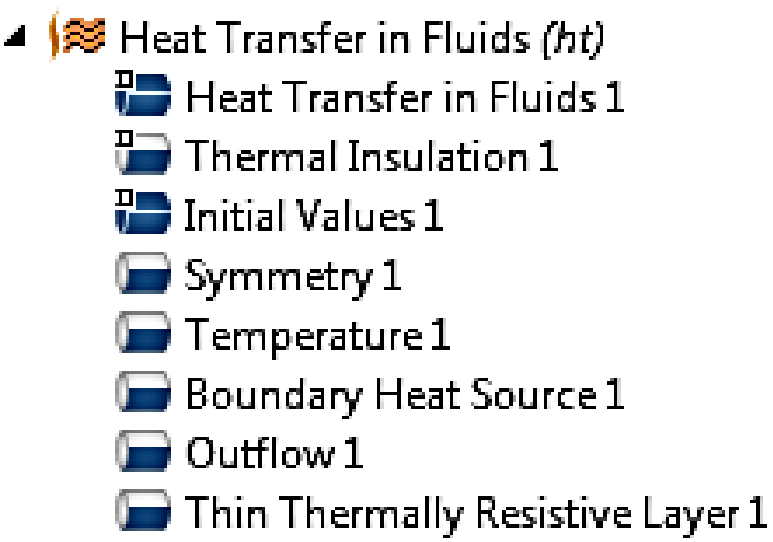


Thermal equations

- We use the **Heat Transfer in Fluids** interface.
- Radiation is neglected in this initial studies.
- **GASEOUS SUBDOMAIN:** Heat conduction and convection,

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \vec{u} \cdot \vec{\nabla} T = \vec{\nabla} \cdot (k \vec{\nabla} T)$$

- The velocity field is obtained from the Navier-Stokes equations that are solved in the **Laminar Flow** interface.
- The density and thermal conductivity of the air are related with the temperature.



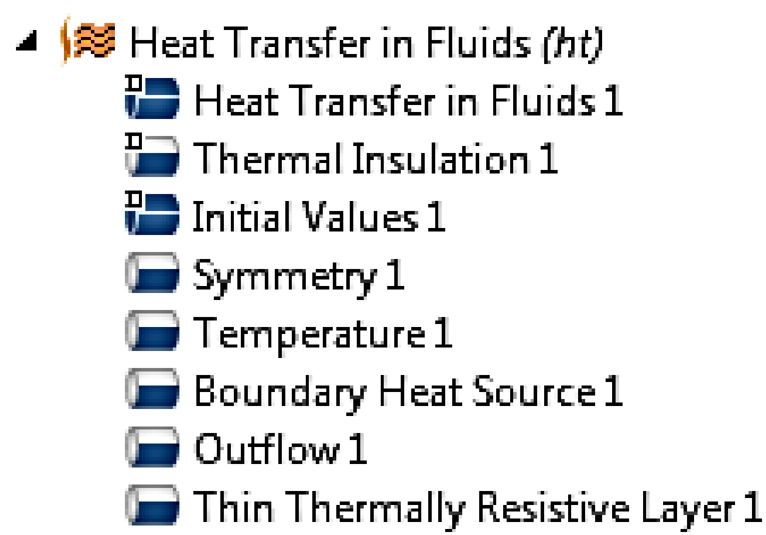
Thermal equations

❑ **PV SOLID INTERIOR BOUNDARY:** Thin thermally resistive layer (4 layers) and boundary heat generation,

$$-\vec{n} \cdot \left(k\vec{\nabla}T\right) = Q_b$$

❑ Q_b has a value that corresponds to the instantaneous incident direct irradiation plus the diffuse radiation.

Material	Thickness	Thermal conductivity
Glass	3 mm	1.7 W/(m·K)
Silicon	0.4 mm	0.235 W/(m·K)
EVA	0.8 mm	148 W/(m·K)
Tedlar	0.05 mm	0.158 W/(m·K)



Fluid equations

- They are the corresponding to the **Turbulent Flow, k-ε** interface.
- We have wind conditions and, in this initial calculation, we neglect the **body force** acting on the fluid that corresponds to the buoyancy force due to the dependence of the density of the air with the temperature.

$$\rho\frac{\partial \mathbf{u}}{\partial t} + \rho(\mathbf{u}\cdot\nabla)\mathbf{u} =$$
$$\nabla\cdot\left[-p\mathbf{I} + (\mu+\mu_T)\left(\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right) - \frac{2}{3}(\mu+\mu_T)(\nabla\cdot\mathbf{u})\mathbf{I} - \frac{2}{3}\rho k\mathbf{I}\right] + \mathbf{F}$$

$$\frac{\partial\rho}{\partial t} + \nabla\cdot(\rho\mathbf{u}) = 0$$

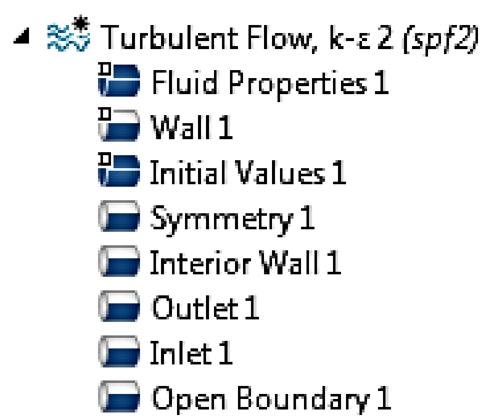
$$\rho\frac{\partial k}{\partial t} + \rho(\mathbf{u}\cdot\nabla)k = \nabla\cdot\left[\left(\mu + \frac{\mu_T}{\sigma_k}\right)\nabla k\right] + P_k - \rho\epsilon$$

$$\rho\frac{\partial \epsilon}{\partial t} + \rho(\mathbf{u}\cdot\nabla)\epsilon = \nabla\cdot\left[\left(\mu + \frac{\mu_T}{\sigma_\epsilon}\right)\nabla \epsilon\right] + C_{\epsilon 1}\frac{\epsilon}{k}P_k - C_{\epsilon 2}\rho\frac{\epsilon^2}{k}, \quad \epsilon = \mathrm{ep}$$

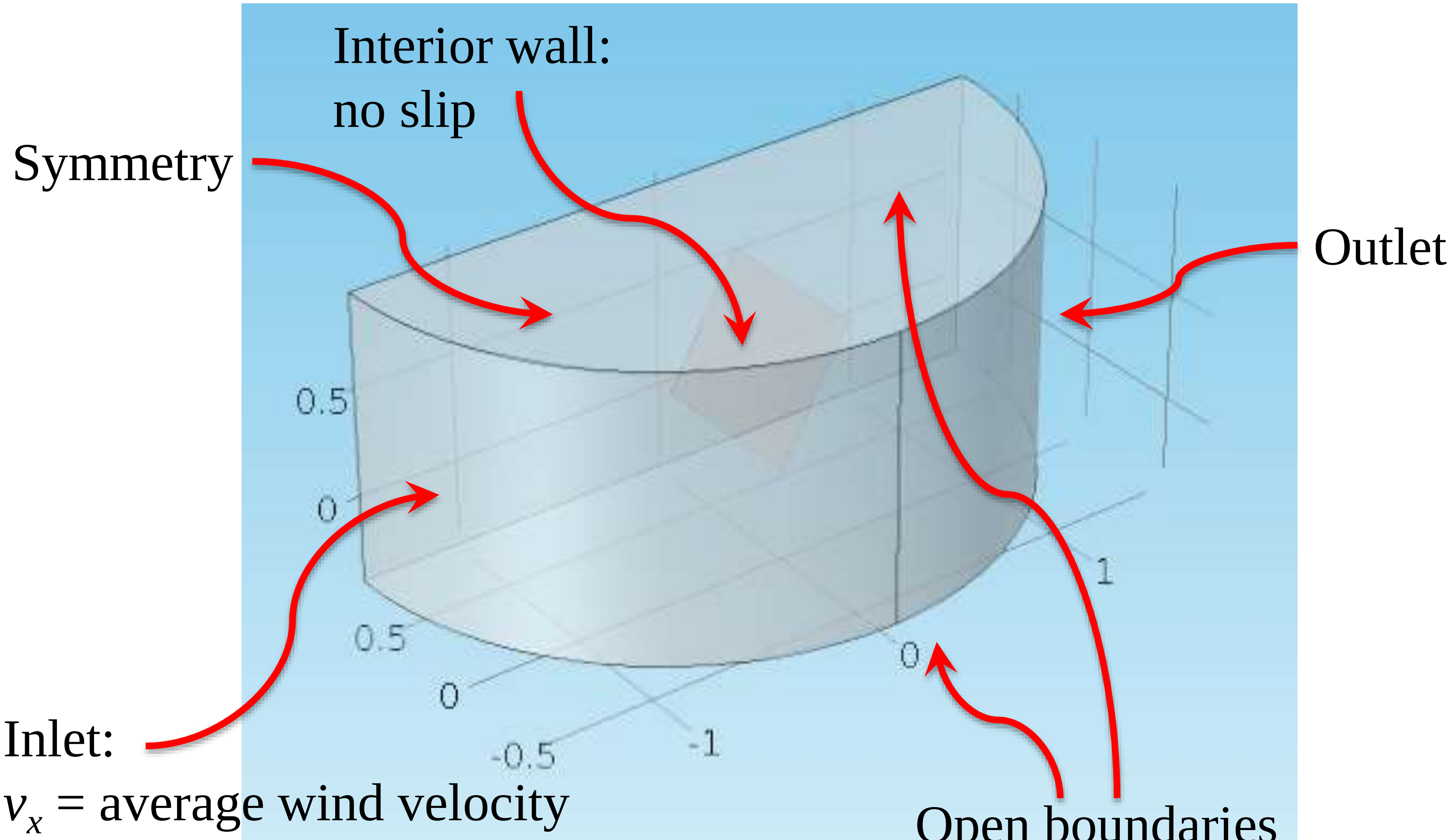
$$\mu_T = \rho C_\mu \frac{k^2}{\epsilon}$$

$$P_k = \mu_T\left[\nabla\mathbf{u} : \left(\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right) - \frac{2}{3}(\nabla\cdot\mathbf{u})^2\right] - \frac{2}{3}\rho k\nabla\cdot\mathbf{u}$$

Re is approximately 60000



Fluid Boundary Conditions

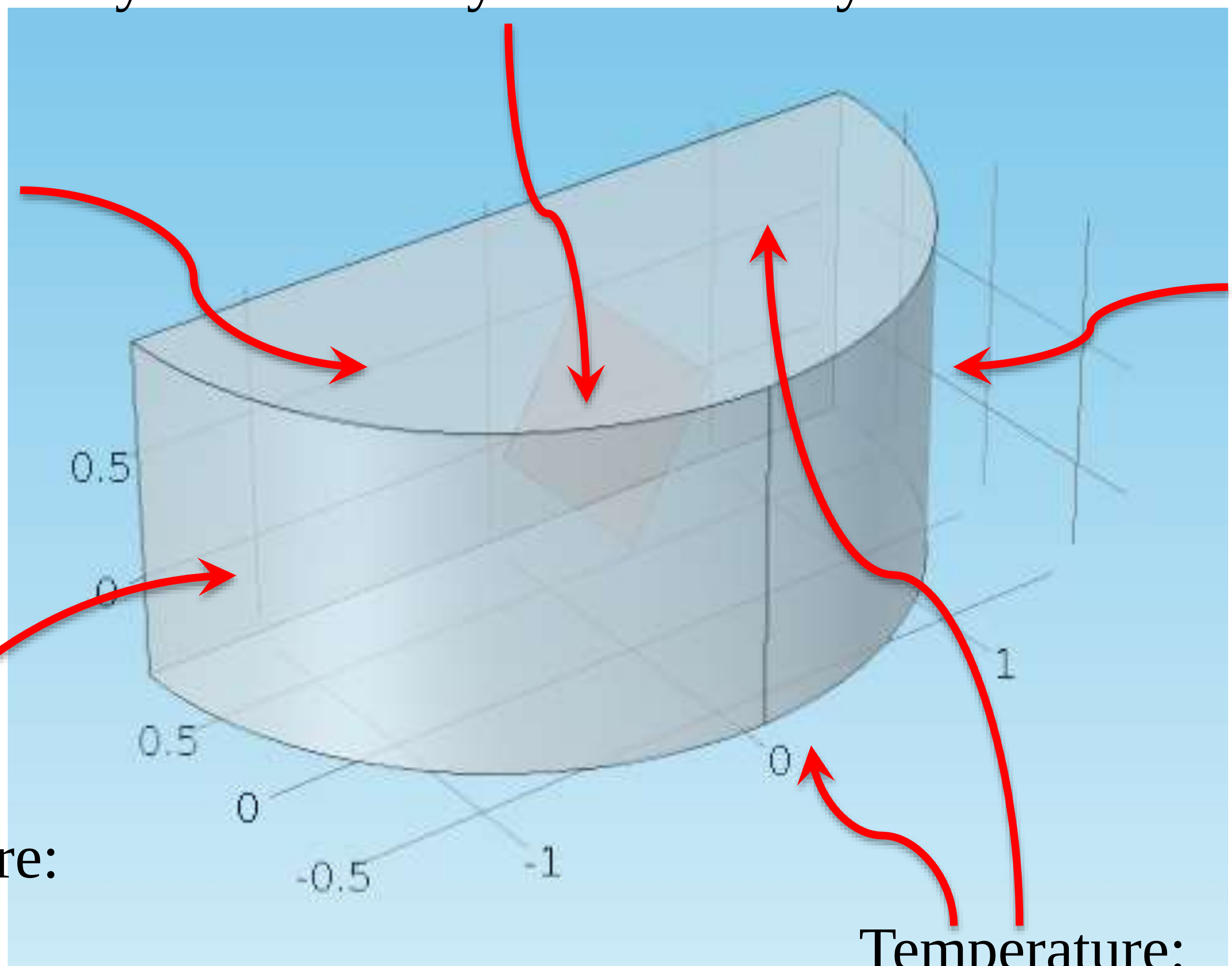


Thermal Boundary Conditions

Thin Thermally Resistive Layer & Boundary Heat Source

Symmetry

Outflow



Temperature: $T_{amb}(t)$

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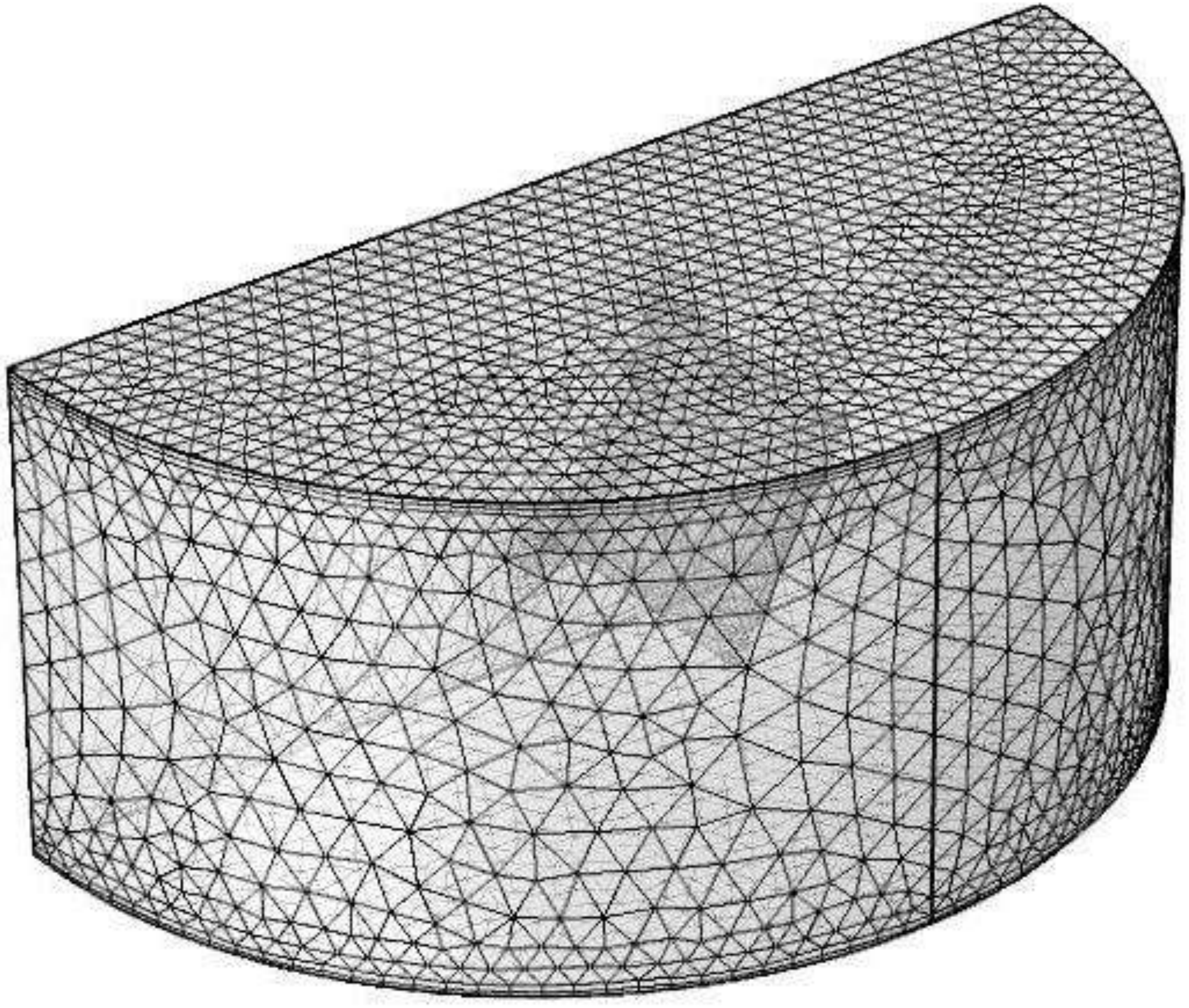
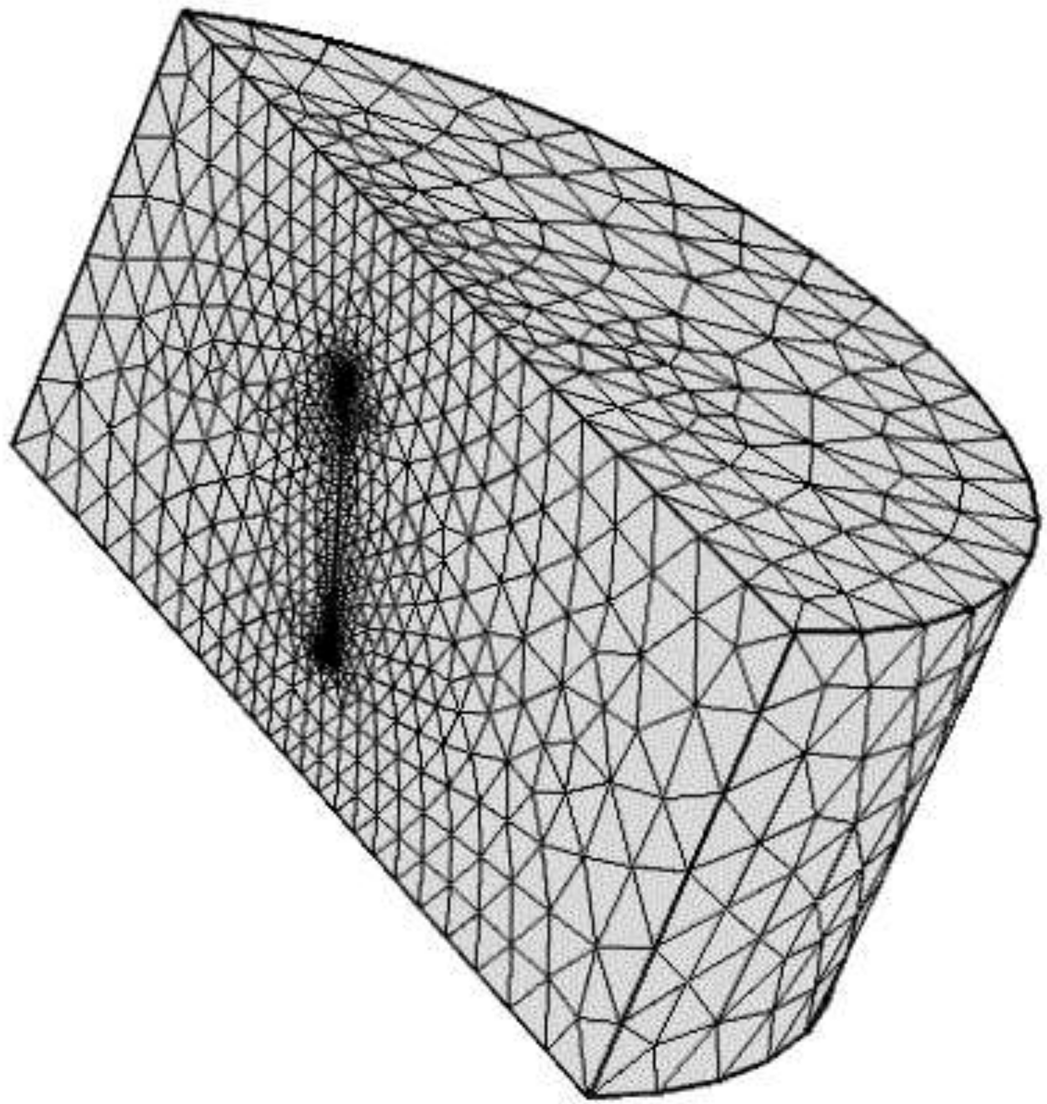
Mesh 1



Mesh 2



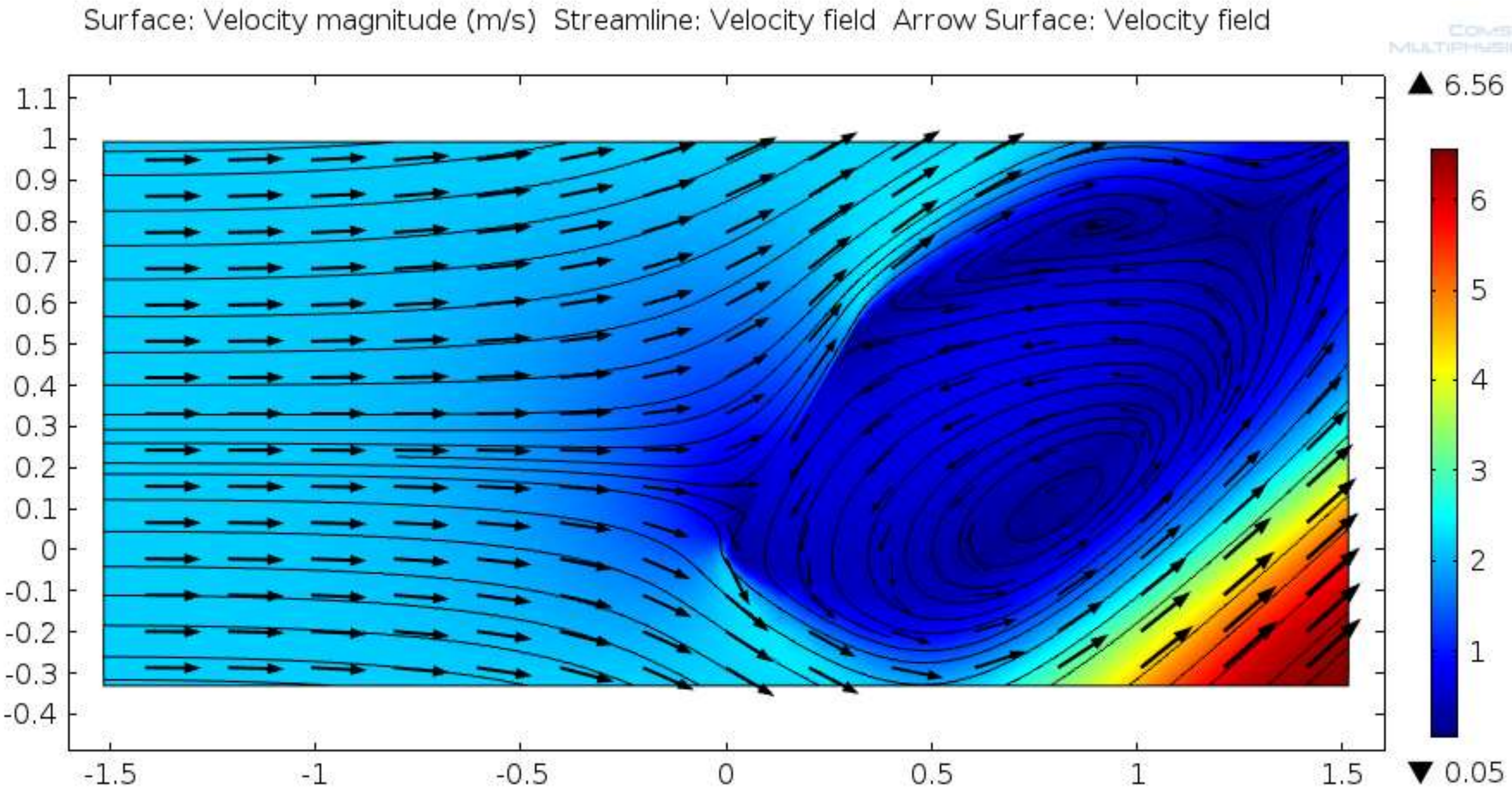
Solution

- We have a one-direction coupling system.

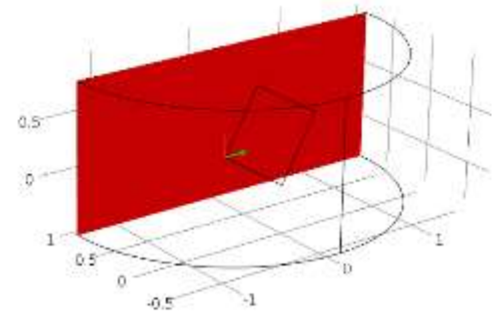
- We use two study time-dependent steps:

  - In the ***first step***, we calculate the air velocity field under the averaged inlet wind velocity, neglecting the dependence of the air viscosity and density with the temperature.
  - In the ***second step***, we solve for the temperature distribution, by using the velocity field calculated in the previous step.

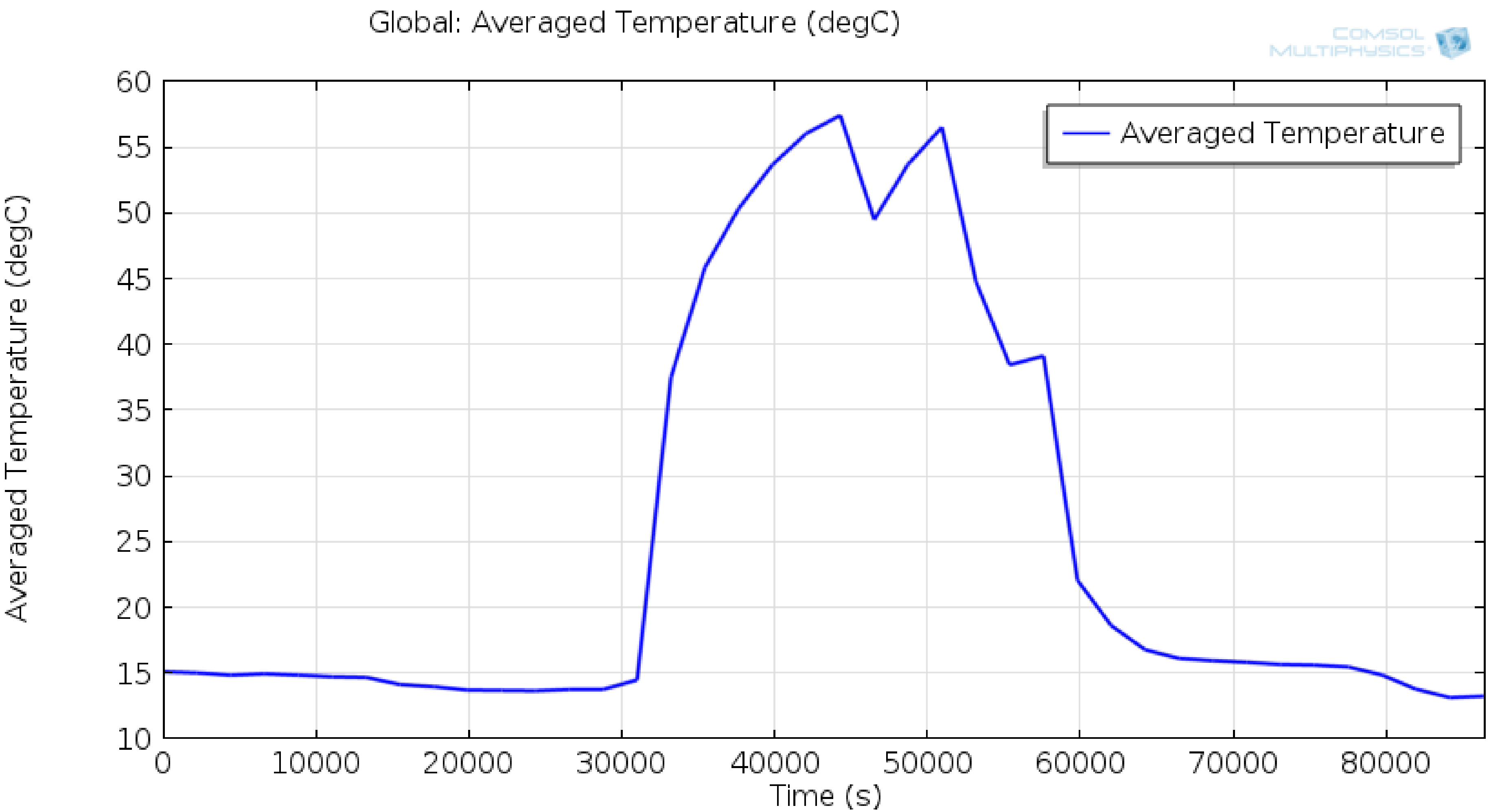
Results



Mid plane velocity field.



Results



Averaged temperature of the solar panel.

Results

From the calculations and measurements, we can observe that:

- The time dependent temperature of the module **agree well** with the values founded in experiments.
- The simulated temperature of the module is **a little bit higher than the measured ones**.
- **The temperature differences** from different points in the panel is about 2 ºC – 3 ºC.
- **There are two air vortexes,** with roughly 30 cm – 40 cm diameter, downstream behind the module.

Conclusions

- We have shown the **use of COMSOL Multiphysics** in the thermal simulation of a photovoltaic module.
- From the numerical results, **we can extract information** about the temperature fields and heat transfer with the ambient medium.
- In particular, this procedure **could be applied in the determination of the heat coefficients of photovoltaic modules** made with different technologies, under several installation conditions and wind speeds.

Future work

- We have started with a very simple simulation and we now have to:
  - Include the effect of the time-dependent wind velocity.
  - Take into account the variable wind direction.
  - Make the strong coupling.
  - Introduce the more complex geometry of the solar tracker system.

Bibliography

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Acknowledgements

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Thank you very much for your attention!

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