

THERMO-OPTICAL OPTIMIZATION OF LINEAR FRESNEL RECEIVERS

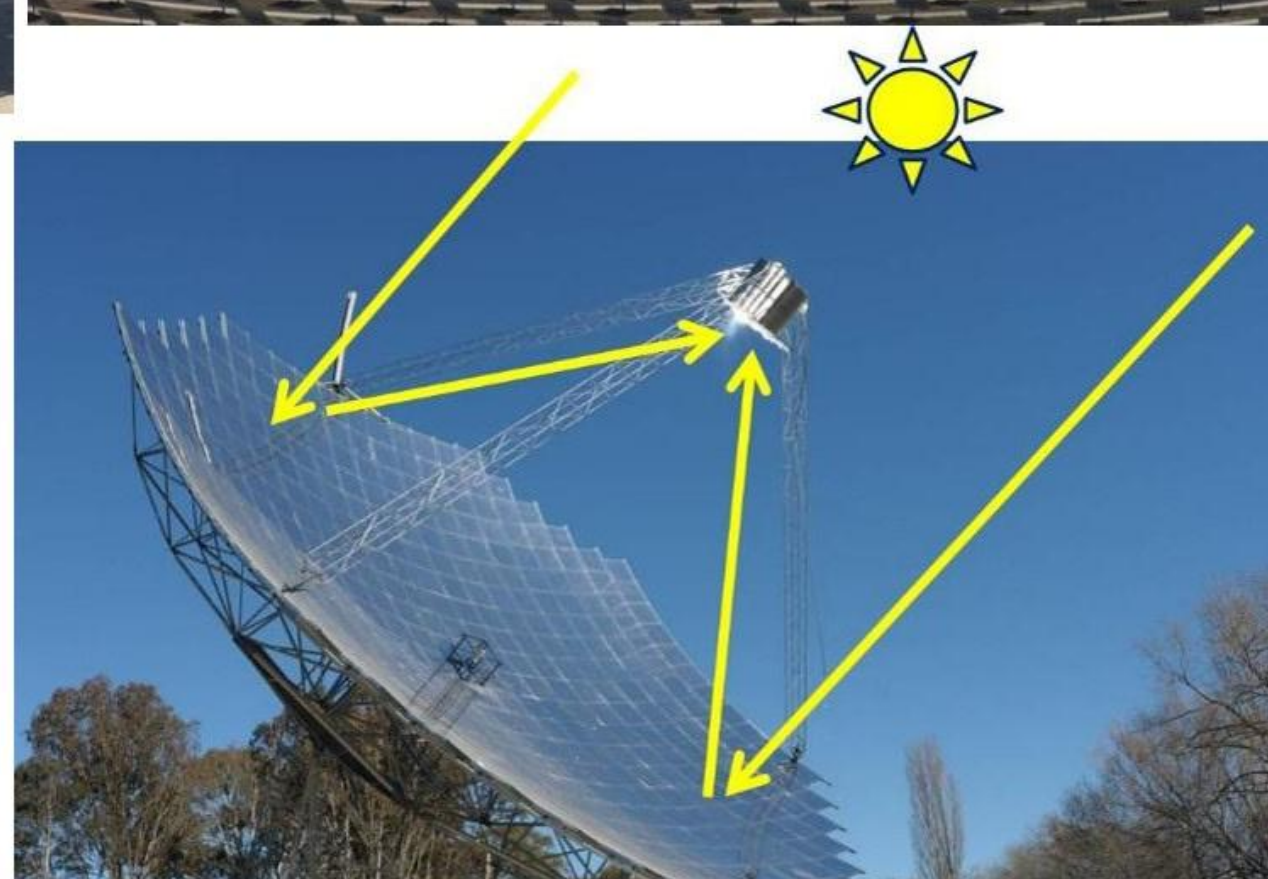
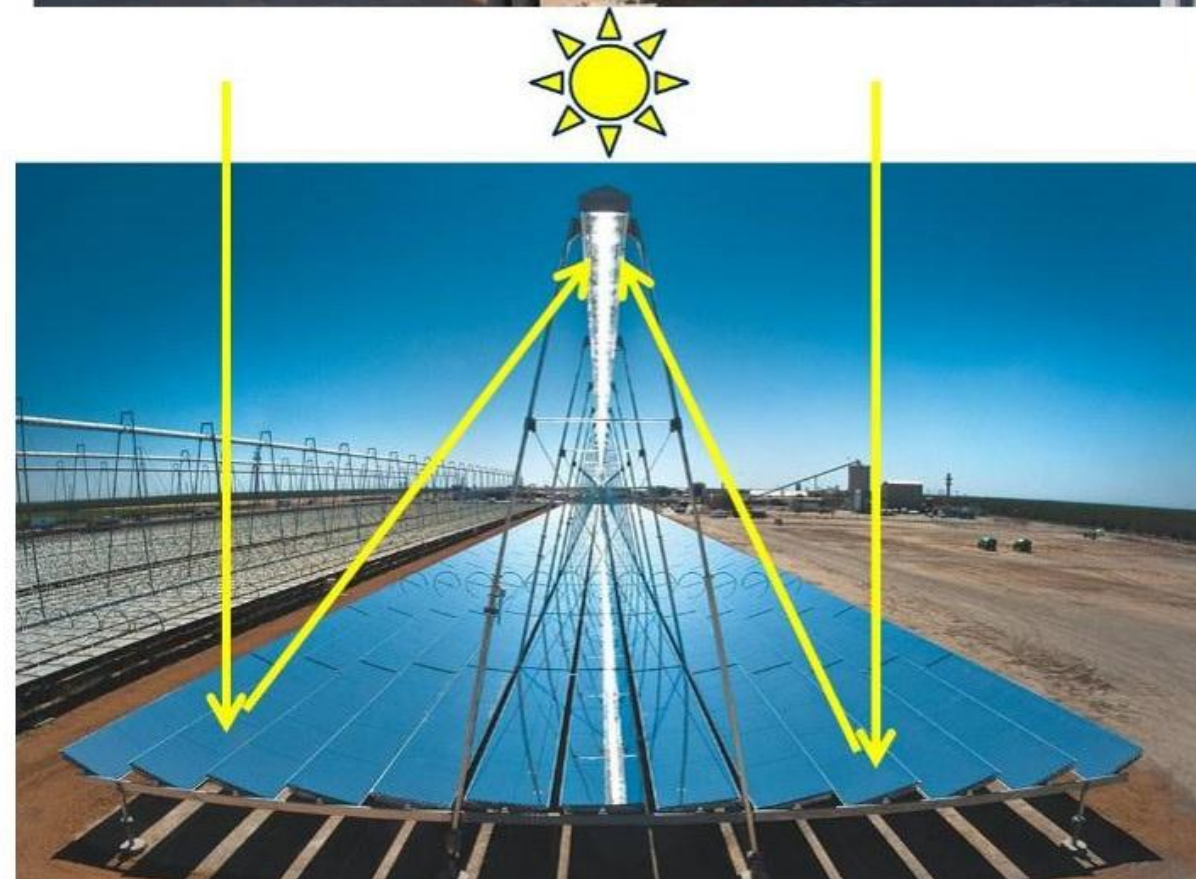
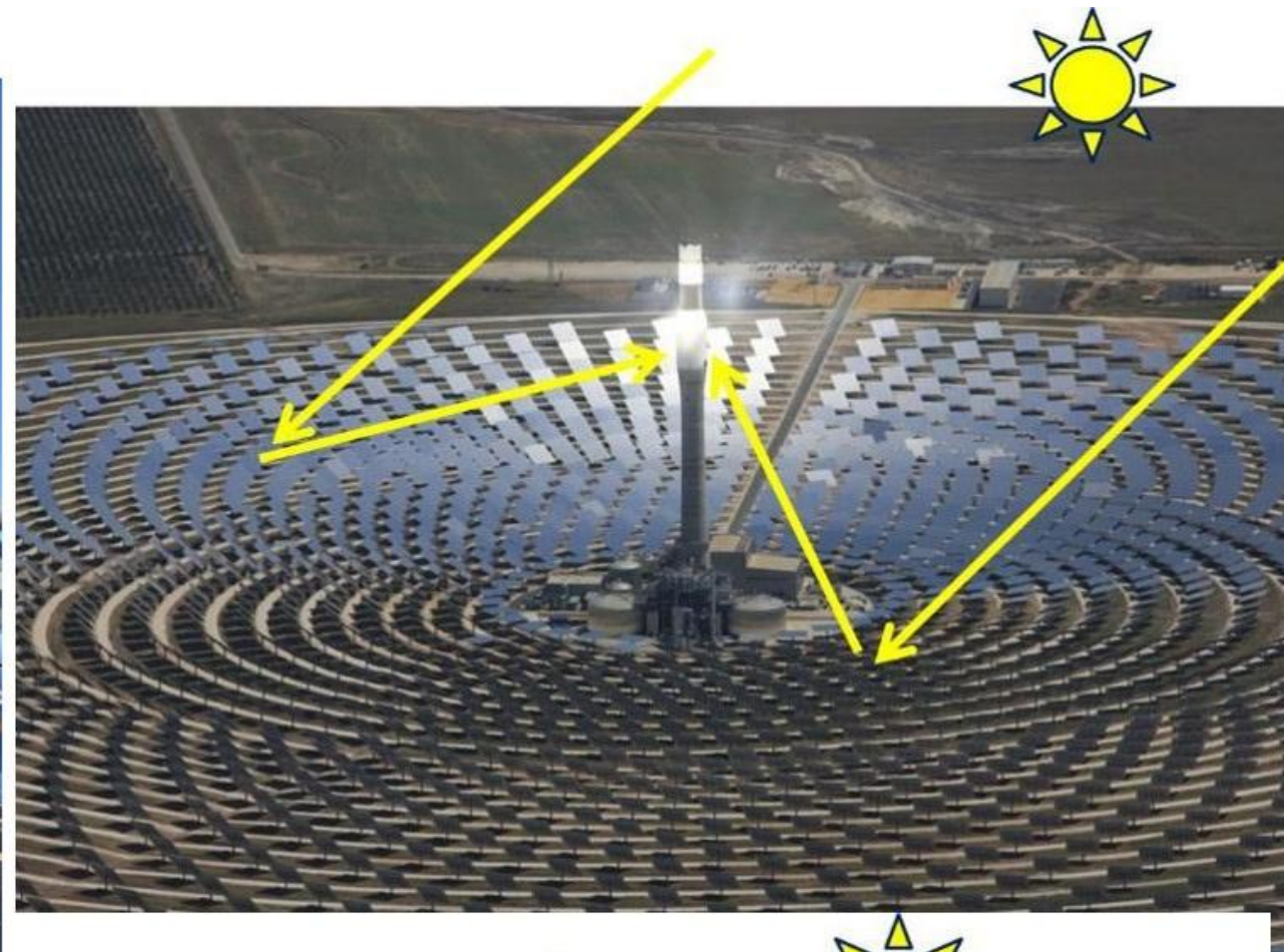
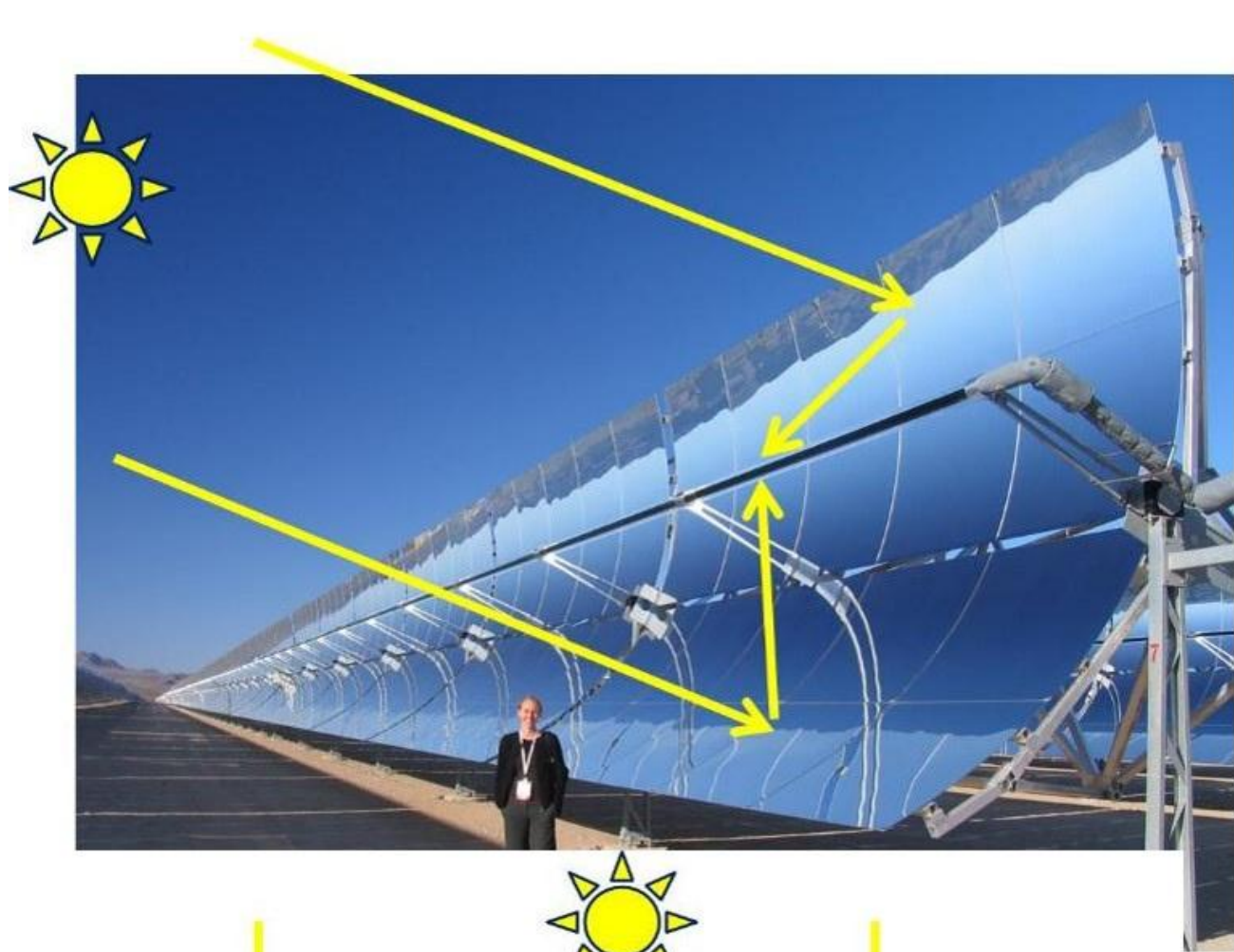
**ENHANCED DURABILITY AND PERFORMANCE – FROM CONCEPT TO
EXPERIMENTAL VALIDATION**

**V4 EnergyNet: Academic Networking for Renewable Energy
and Smart Power Systems.**

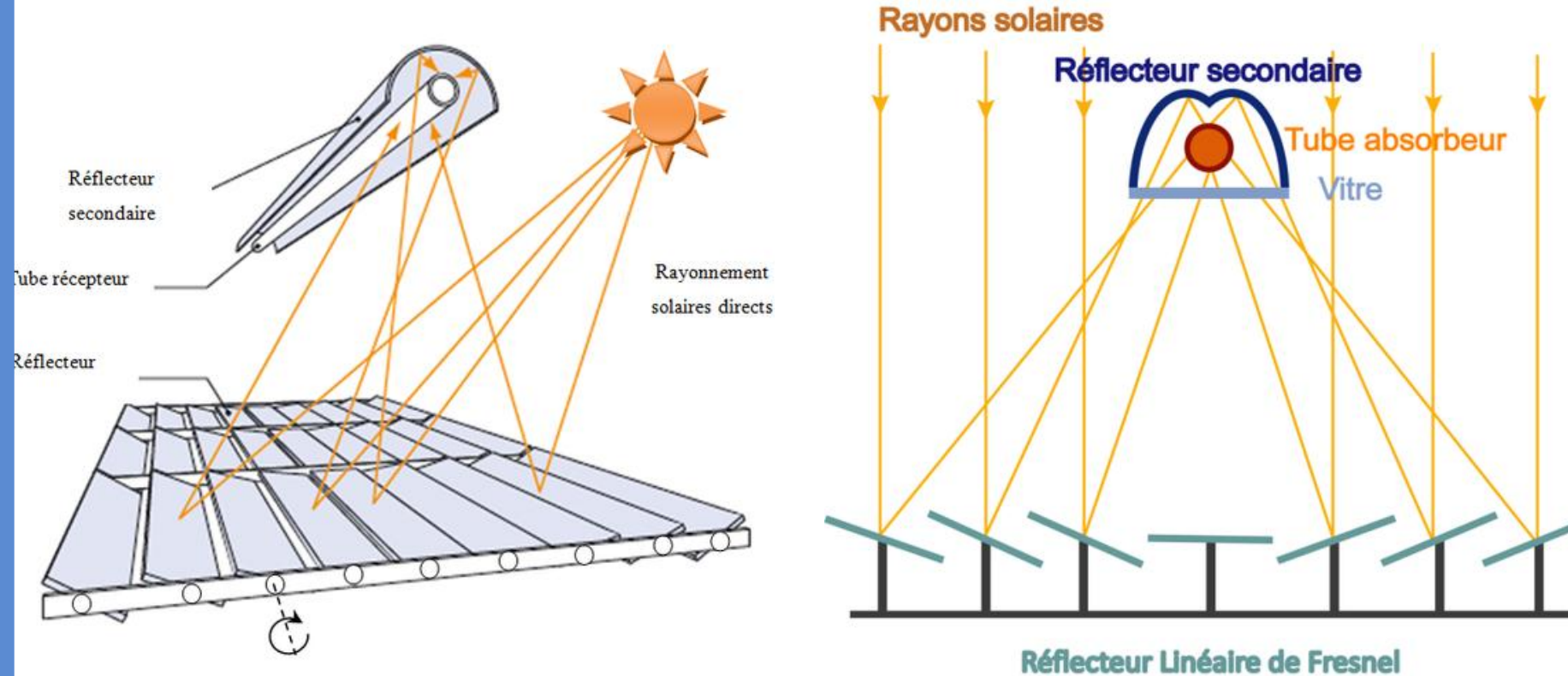
Presented by: Salman Brbhan

**University of Miskolc | Faculty of Mechanical Engineering and Informatics | Energy
Engineering and Chemical Machinery | Department of Chemical Machinery**

Supervisor: Dr. Zoltán Szamosi

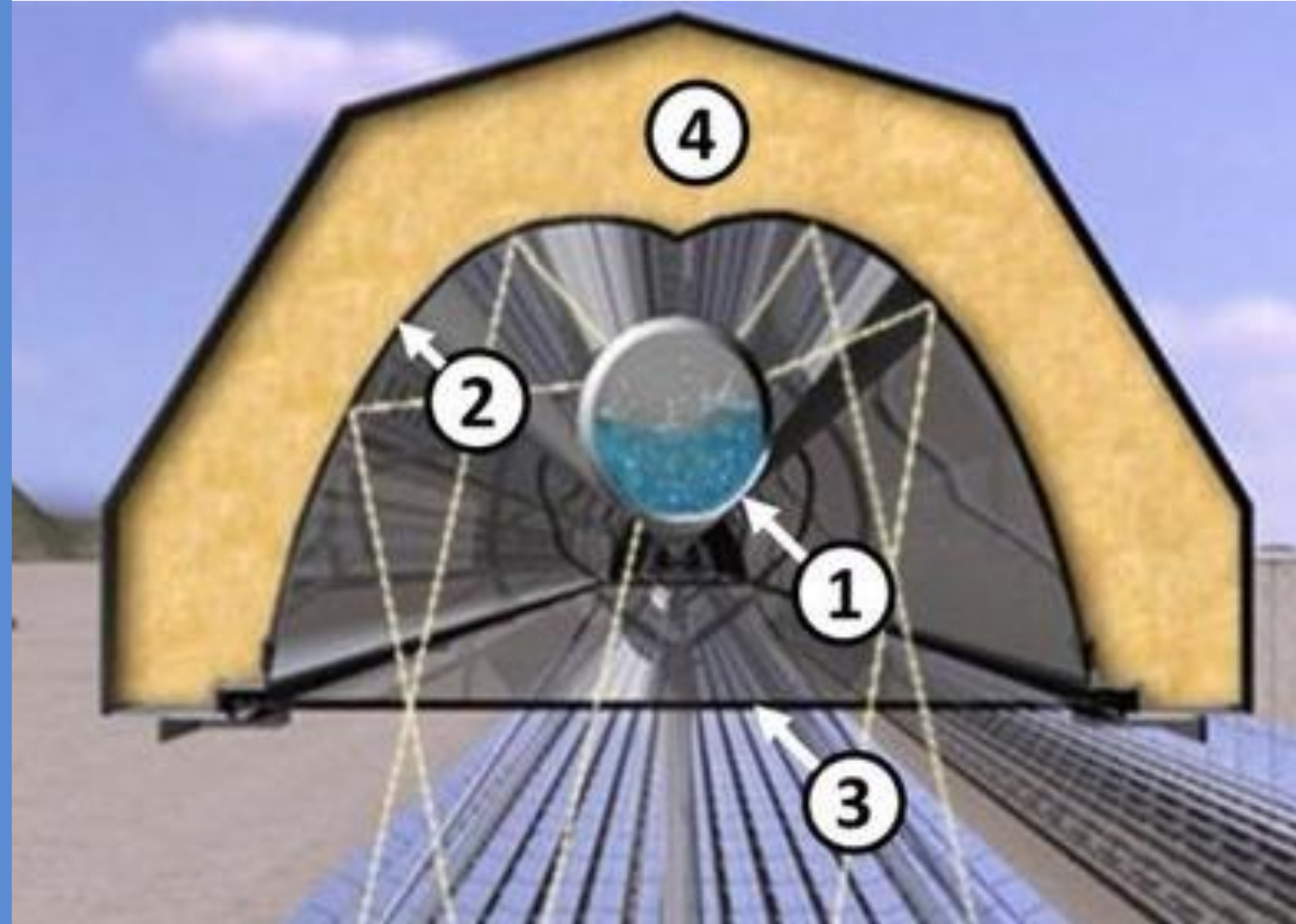


Concentrating Solar Power System (CSP)



Why Fresnel-type CSP system?

- Flat or slightly curved mirrors are less expensive.
- More efficient use of ground space.
- Less susceptible to wind damage.
- Cleaning the mirrors is simpler
- Low cost





CHAPTER 1

Optical and thermal assessment of single- and dual-tube non-vacuum receivers



Governing equations

❖ Convection (air cavity)

□ Equation mass conservation :

$$\frac{\partial \rho u}{\partial x} + \frac{\partial \rho v}{\partial y} = 0$$

□ Equations of momentum conservation:

$$\frac{\partial \rho u^2}{\partial x} + \frac{\partial \rho uv}{\partial y} = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left(\mu \frac{\partial u}{\partial x} \right) + \frac{\partial}{\partial y} \left(\mu \frac{\partial u}{\partial y} \right)$$

$$\frac{\partial \rho uv}{\partial x} + \frac{\partial \rho v^2}{\partial y} = -\frac{\partial p}{\partial y} + \frac{\partial}{\partial x} \left(\mu \frac{\partial v}{\partial x} \right) + \frac{\partial}{\partial y} \left(\mu \frac{\partial v}{\partial y} \right) - g(\rho - \rho_0)$$

□ Equation of energy:

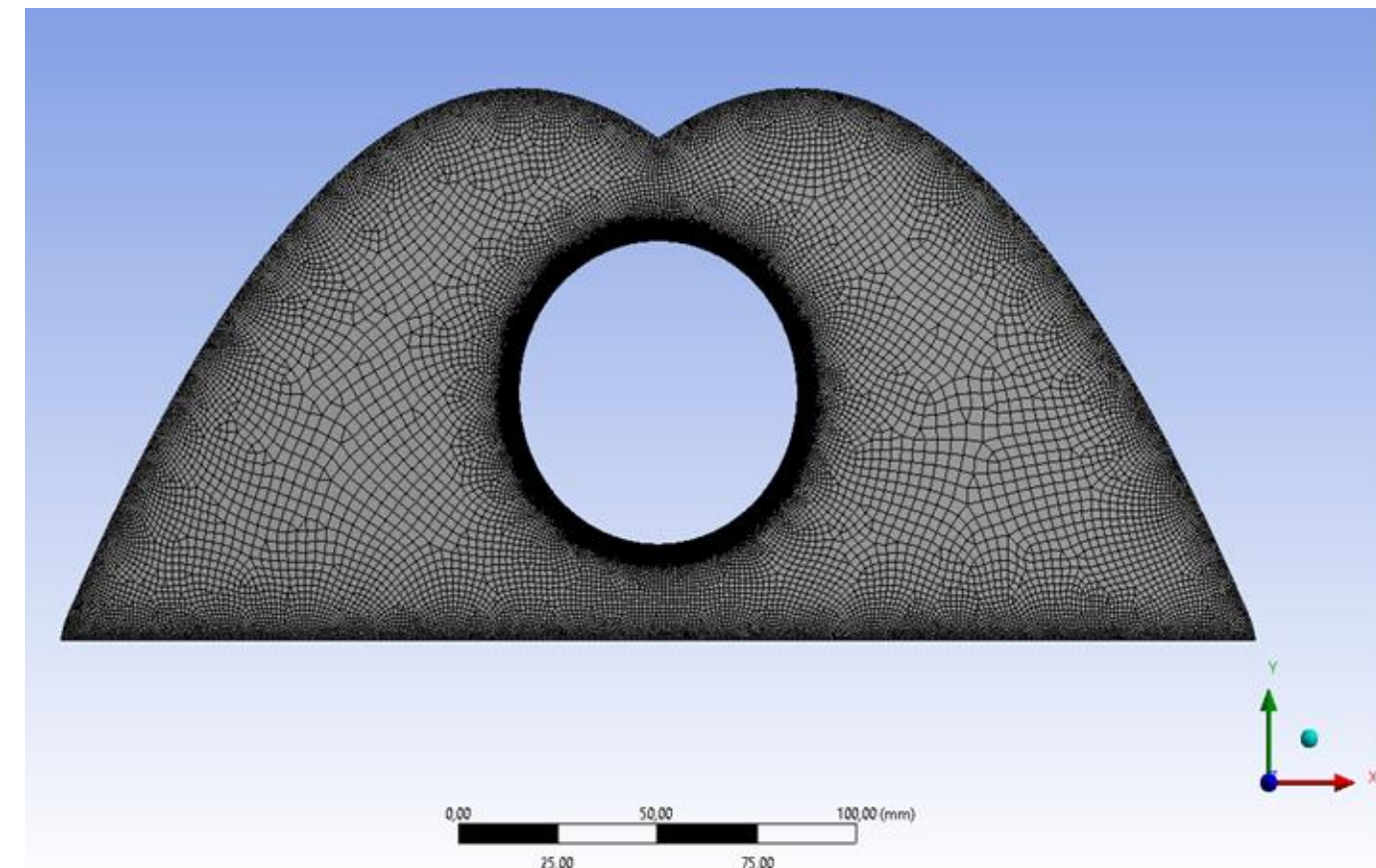
$$u \frac{\partial (\rho c_p T)}{\partial x} + v \frac{\partial (\rho c_p T)}{\partial y} = \frac{\partial}{\partial x} \left(\lambda \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(\lambda \frac{\partial T}{\partial y} \right) + Q$$

❖ Radiation:

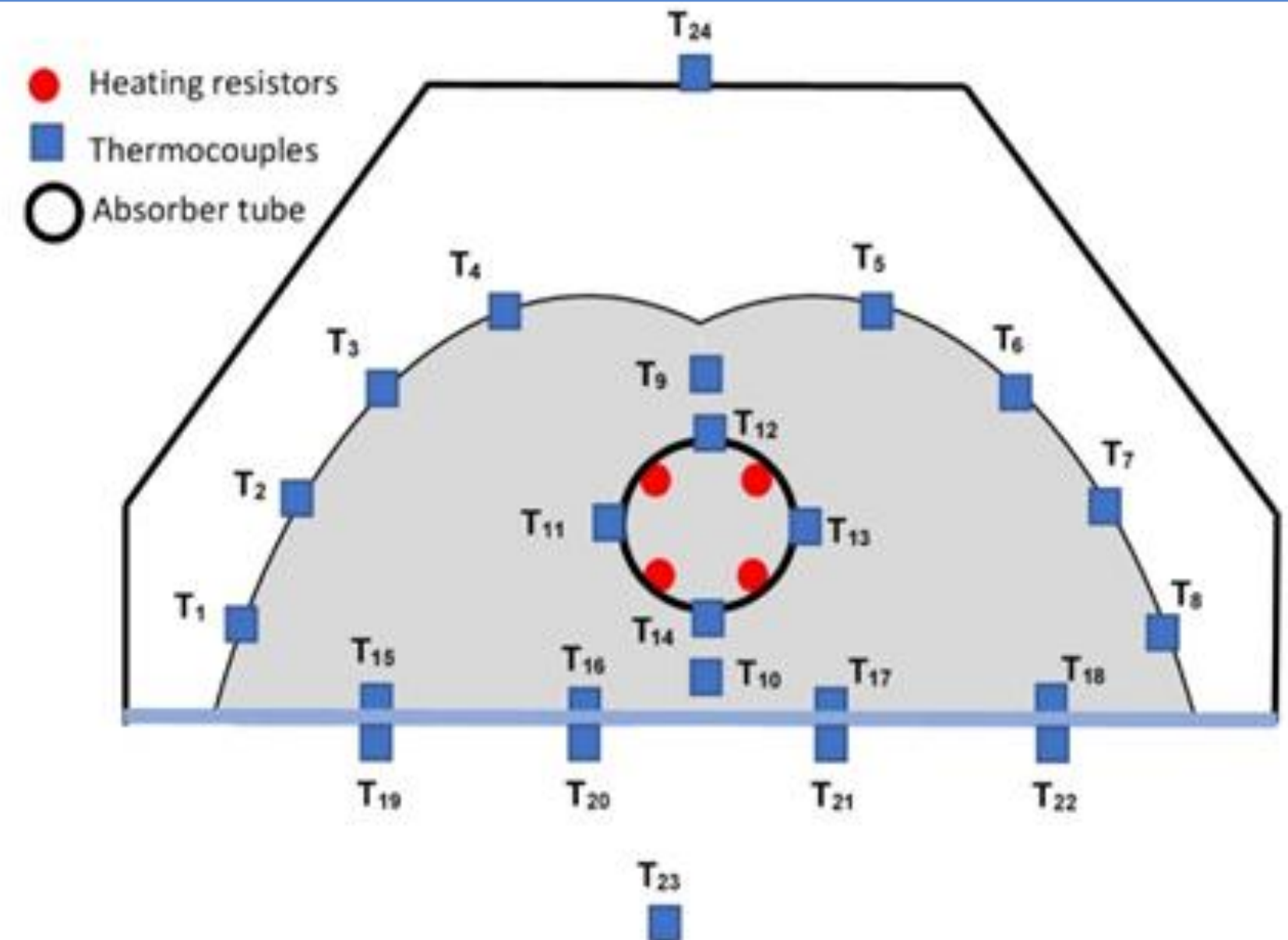
Surface-to-Surface (S2S) Radiation approach is used to simulate heat transfer by radiation where all surfaces are considered as grey bodies

❖ Resolution : Finite Volume Method

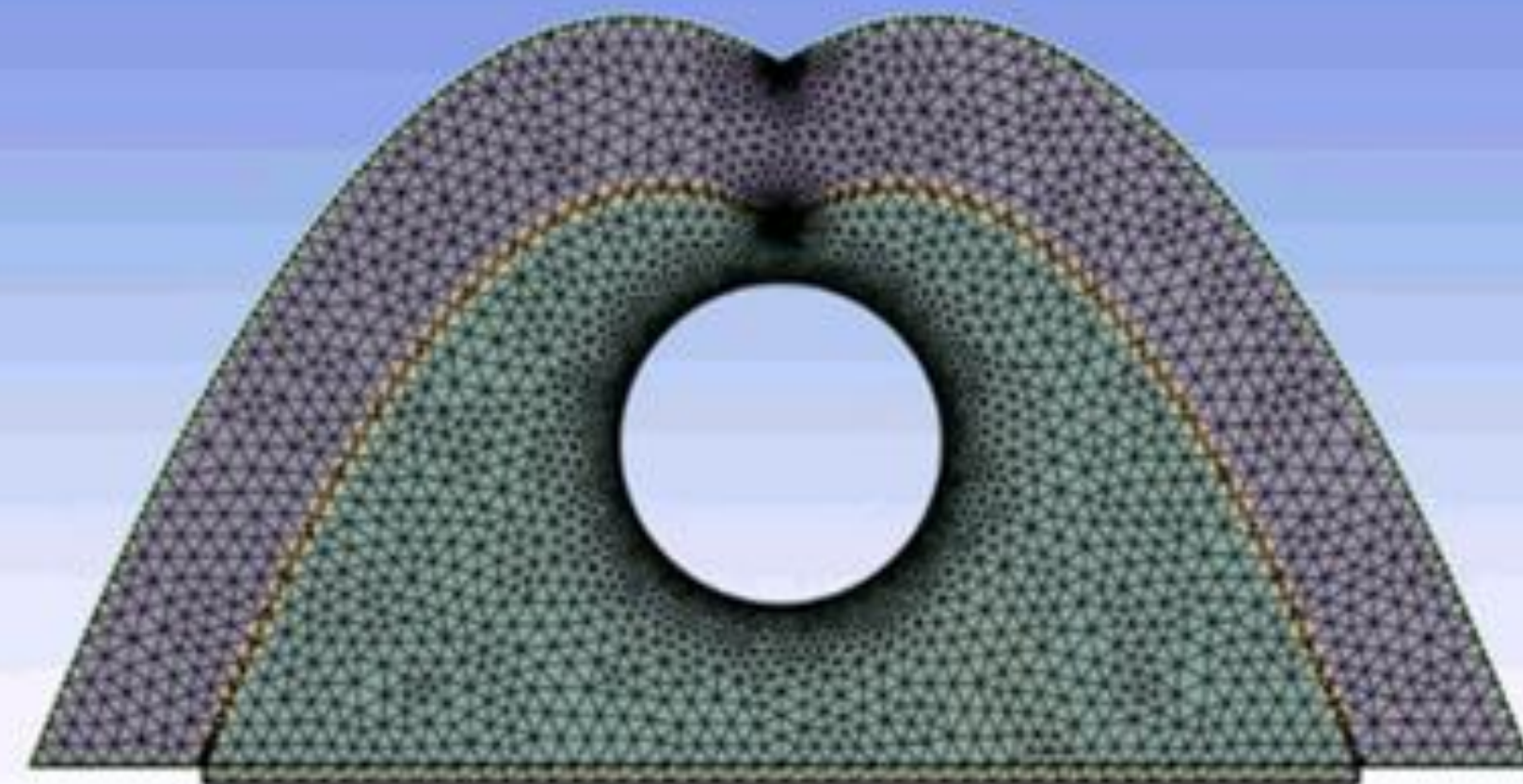
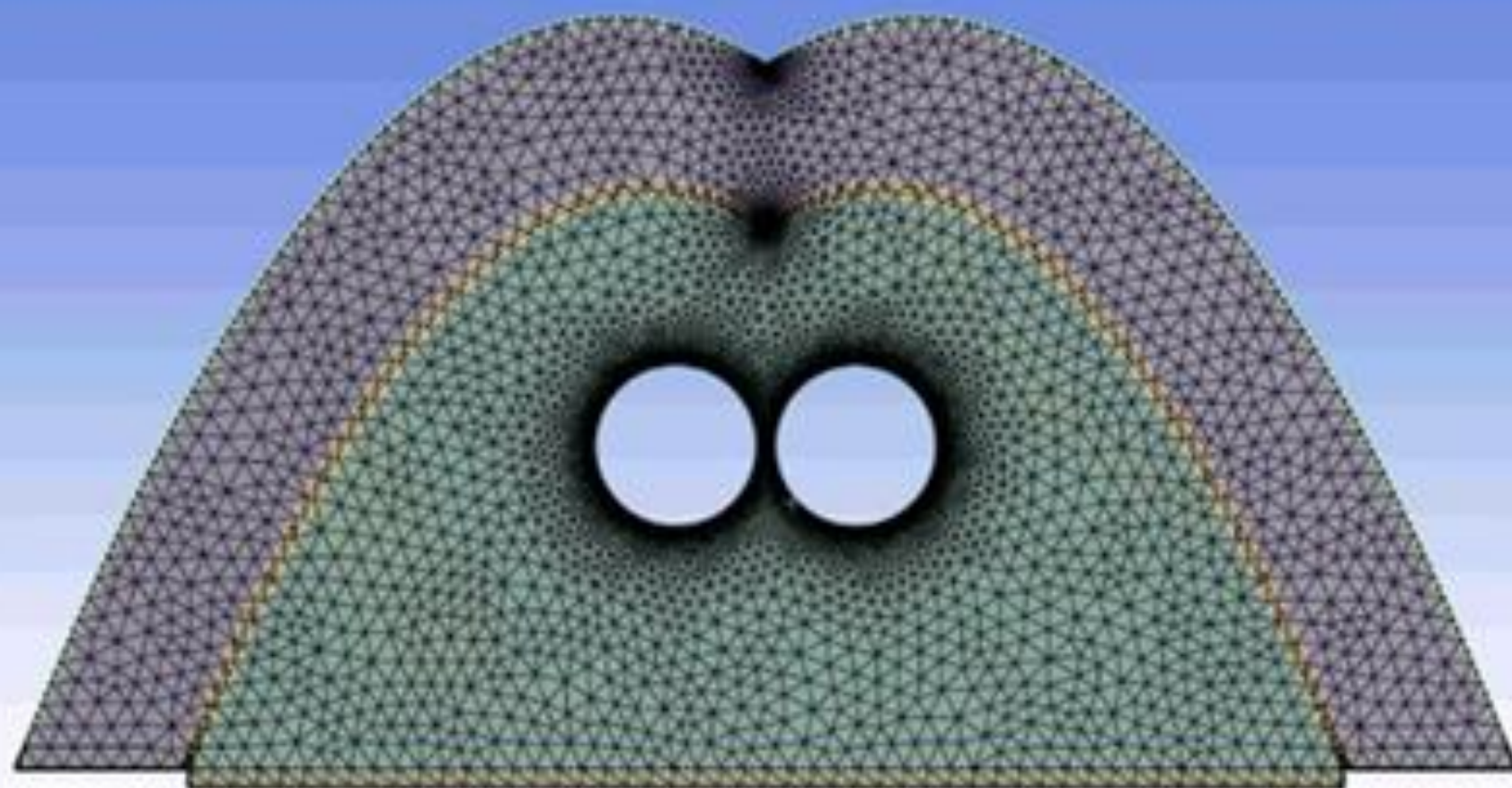
Software: ANSYS-FLUENT



Cross section of the experimental prototype and localization thermocouples and heating resistors

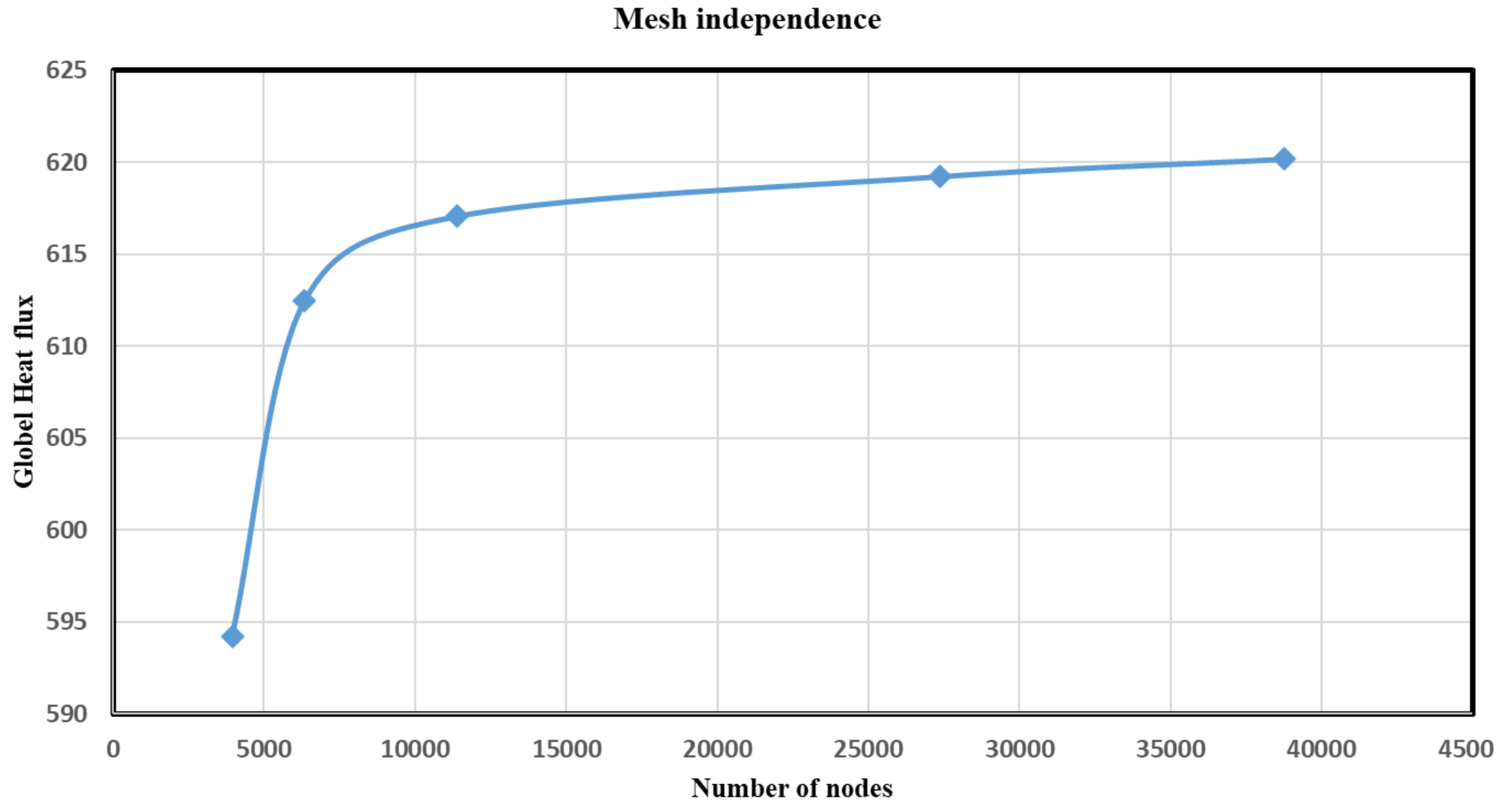


Discretization of the computational domain using triangular elements

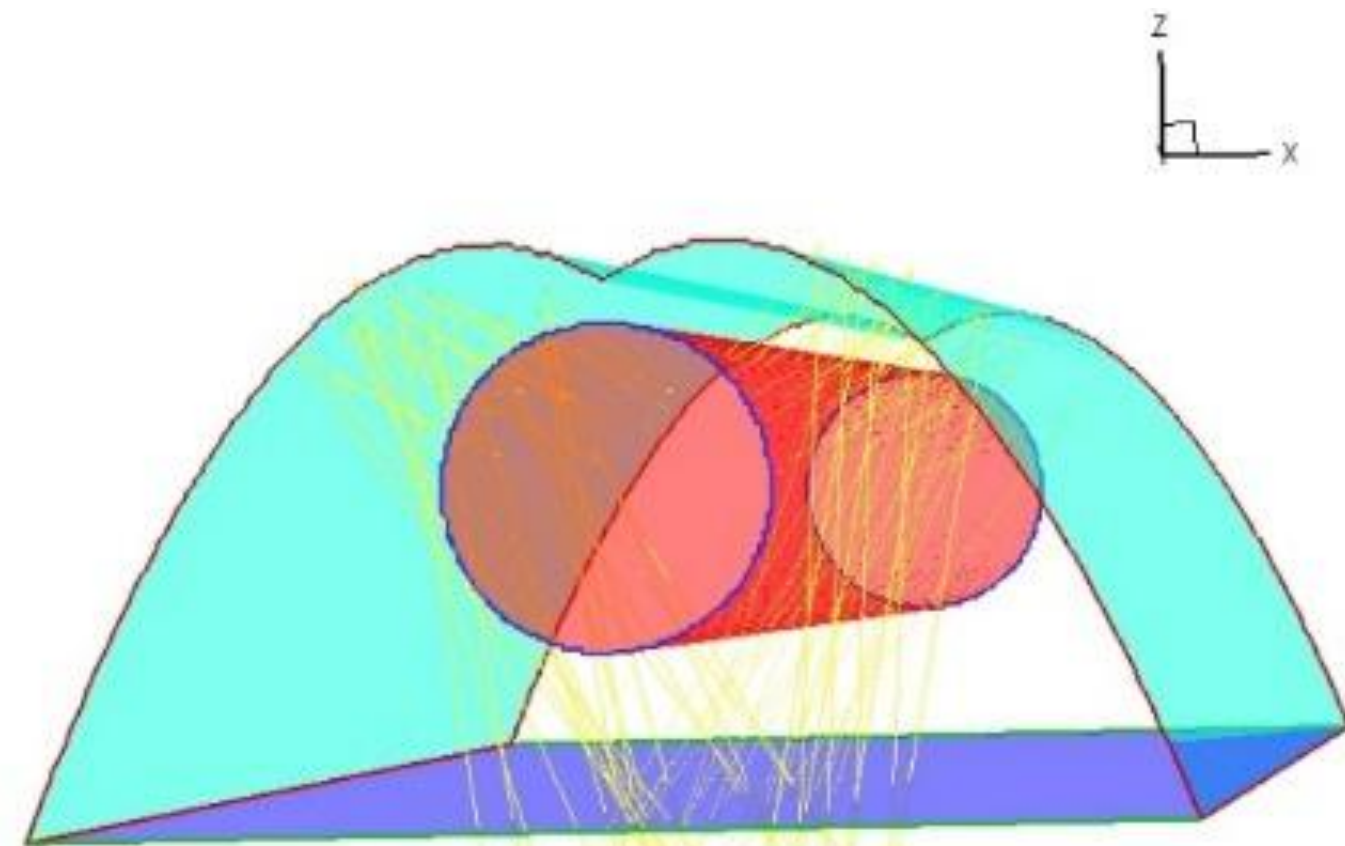
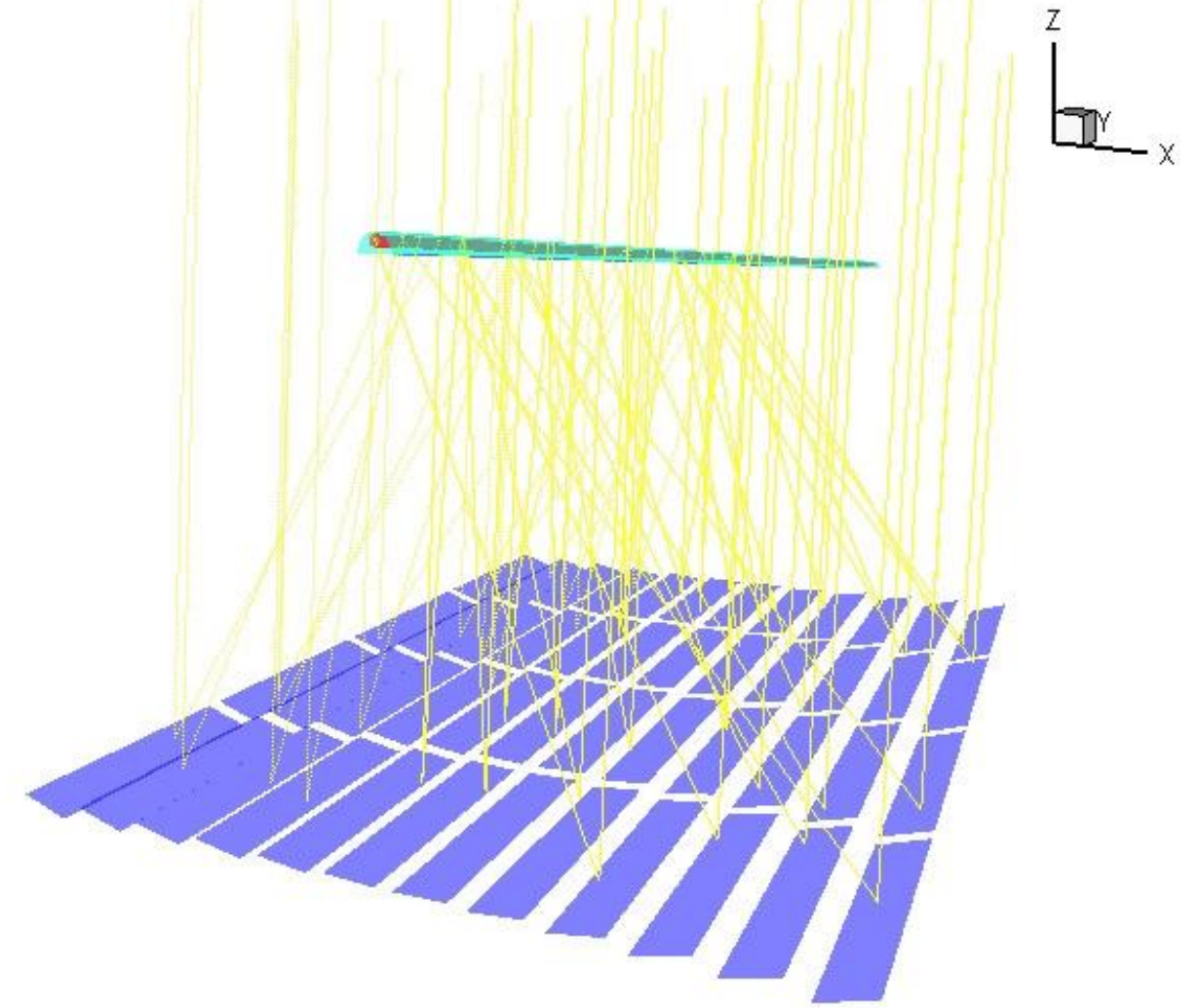
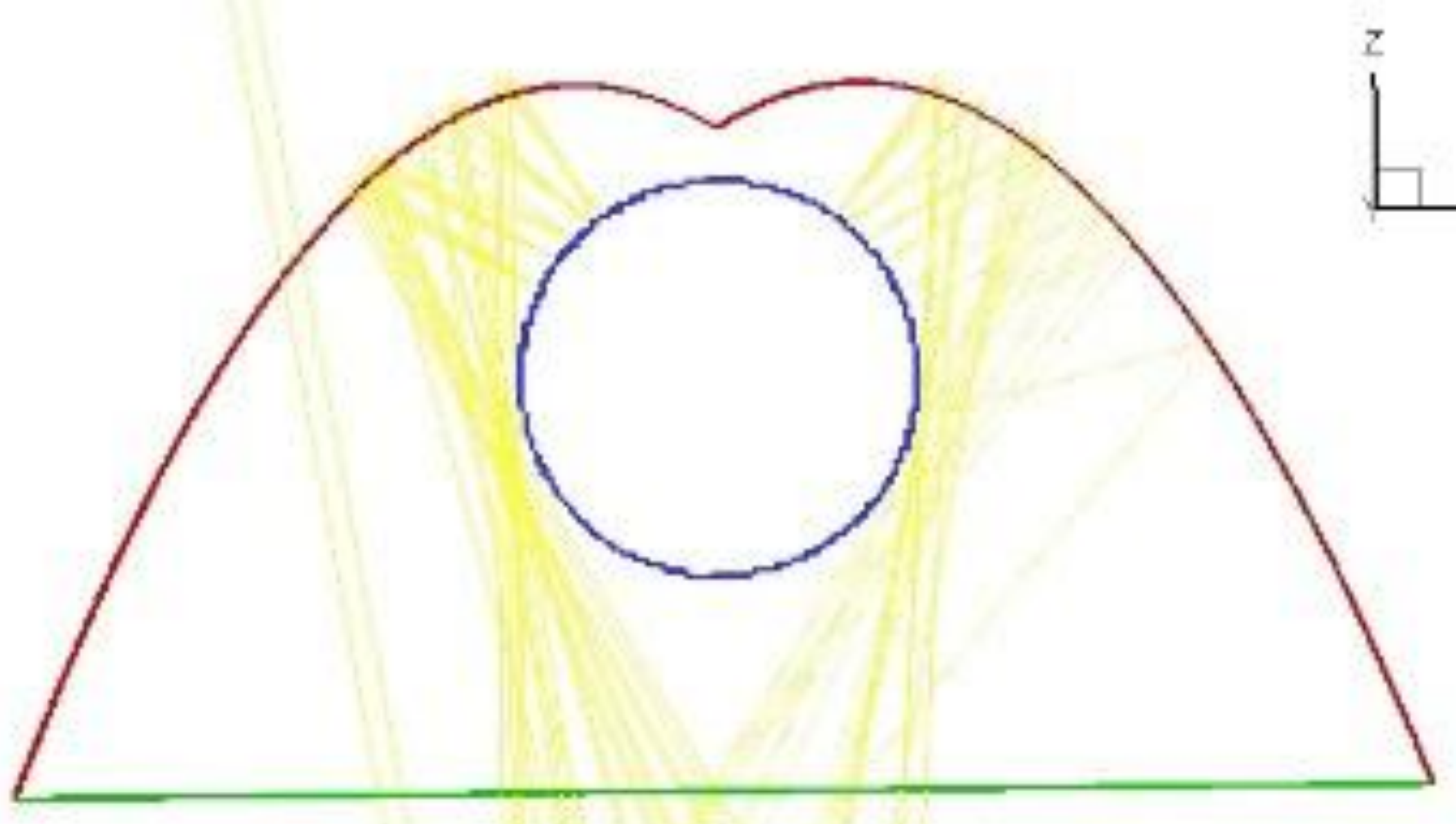


nodes	Global Heat -flux	face size[MM]
3952	594.22	5
6339	612.44	3
11375	617.06	2
27355	619.23	1.2
38778	620.18	1

Independence of the solution to the number of meshing elements



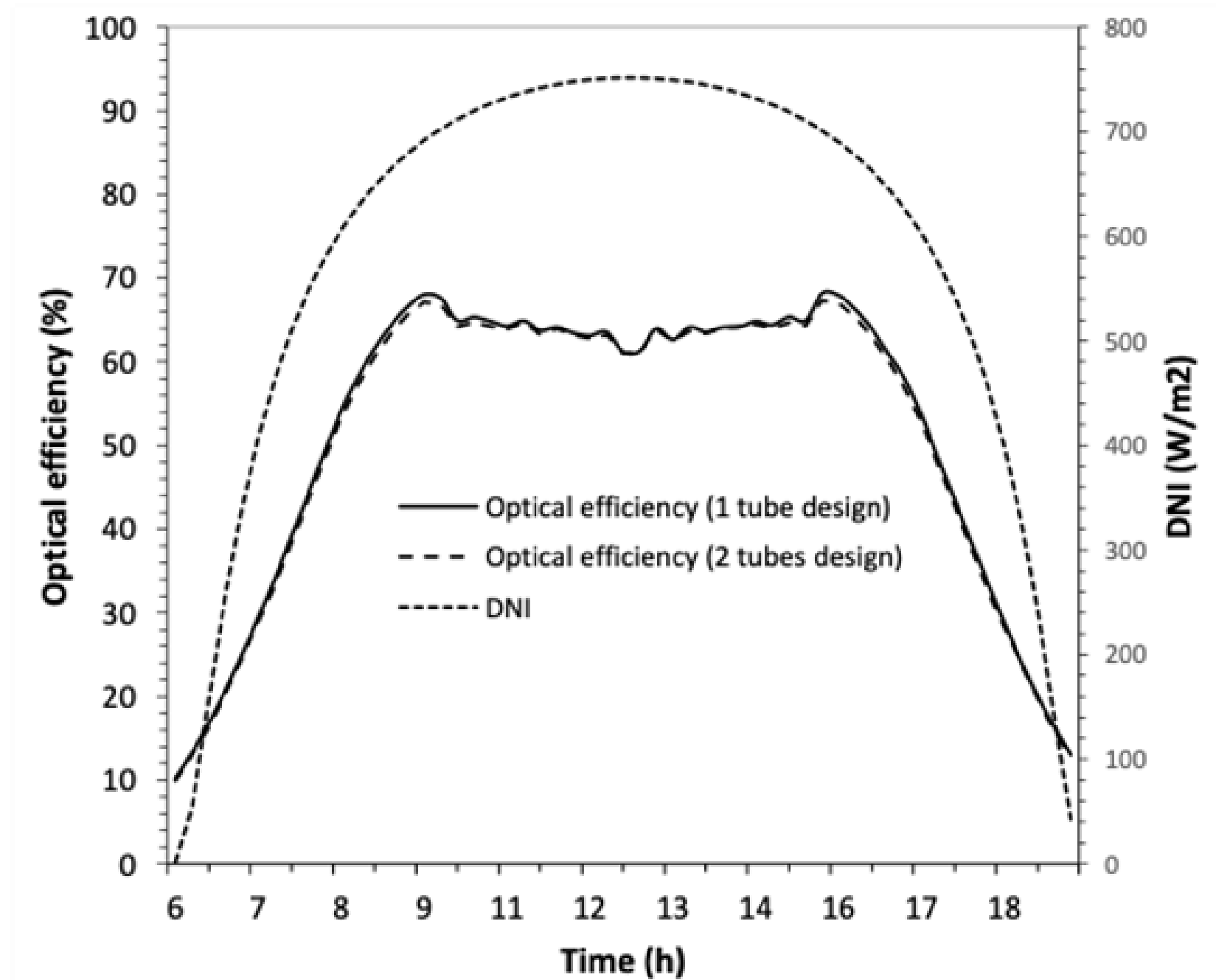
- [-]  Boundary Conditions
 - [-]  Internal
 -  interior-fluid (interior, id=4)
 -  interior-glass (interior, id=5)
 -  interior-insolation (interior, id=1)
 -  interior-secondary (interior, id=3)
 -  interior-tube (interior, id=2)
 - [-]  Wall
 -  interior-insolation-secondary (wall, id=15)
 -  interior-insolation-secondary-shadow (wall, id=23)
 -  tube-external (wall, id=6)
 -  tube-external-shadow (wall, id=22)
 -  tube-internal (wall, id=14)
 -  wall-fluid-glass (wall, id=19)
 -  wall-fluid-glass-shadow (wall, id=8)
 -  wall-fluid-secondary (wall, id=17)
 -  wall-fluid-secondary-shadow (wall, id=21)
 -  wall-glass (wall, id=20)
 -  wall-insolation (wall, id=16)
 -  wall-secondary (wall, id=18)



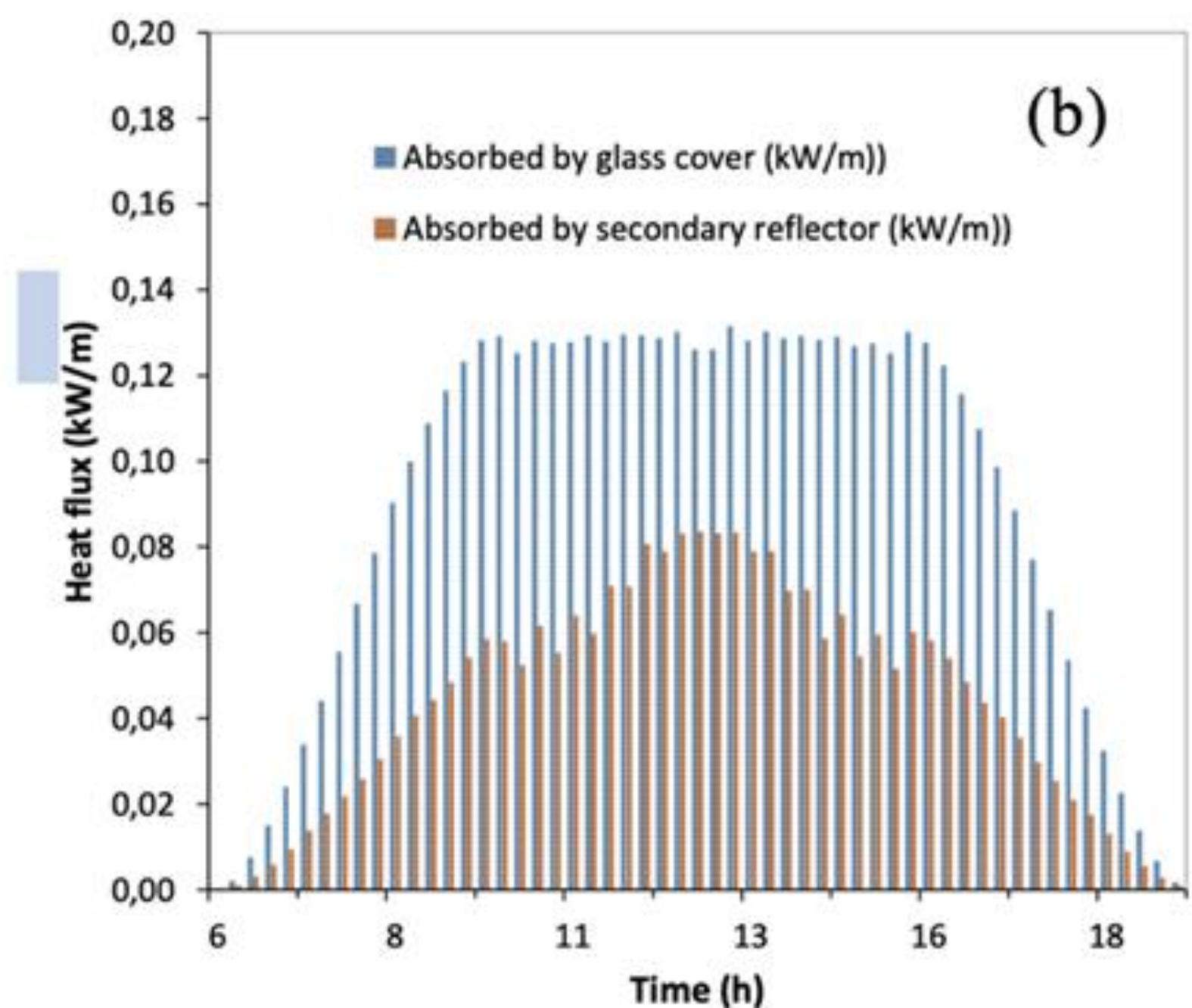
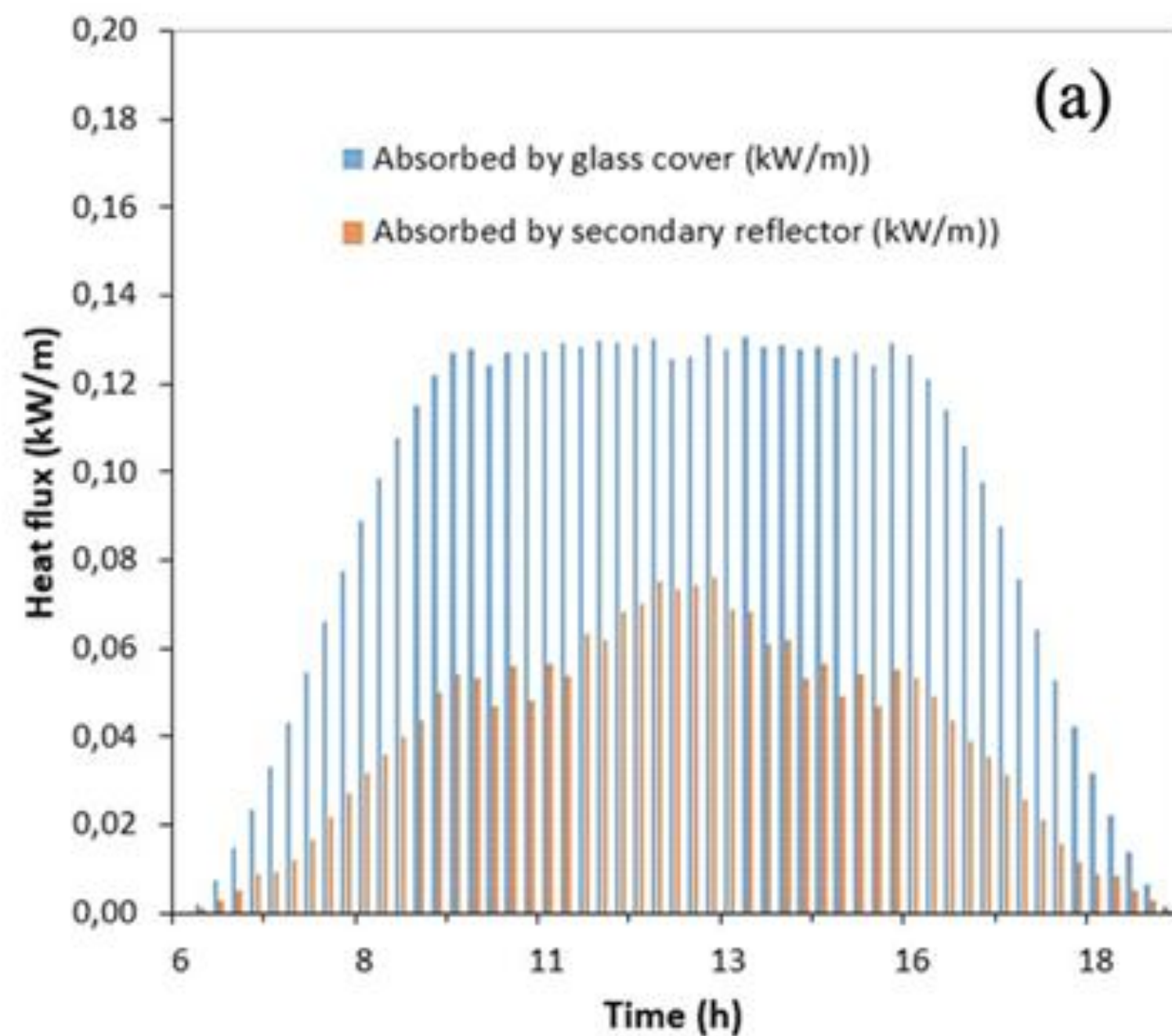
Optical

simulation
Simulation of optical interactions
between sunrays and different LFR
optical components using OPSOL code

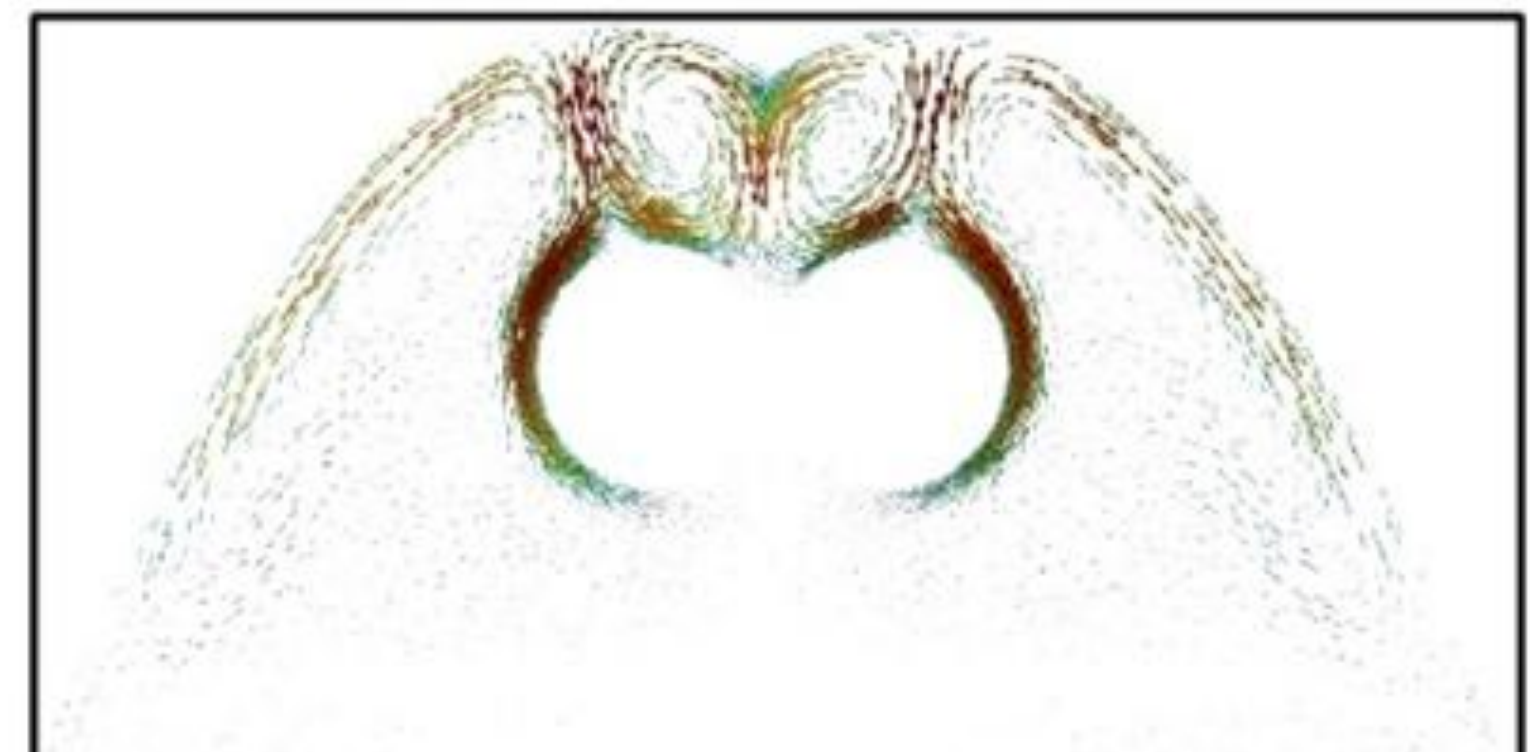
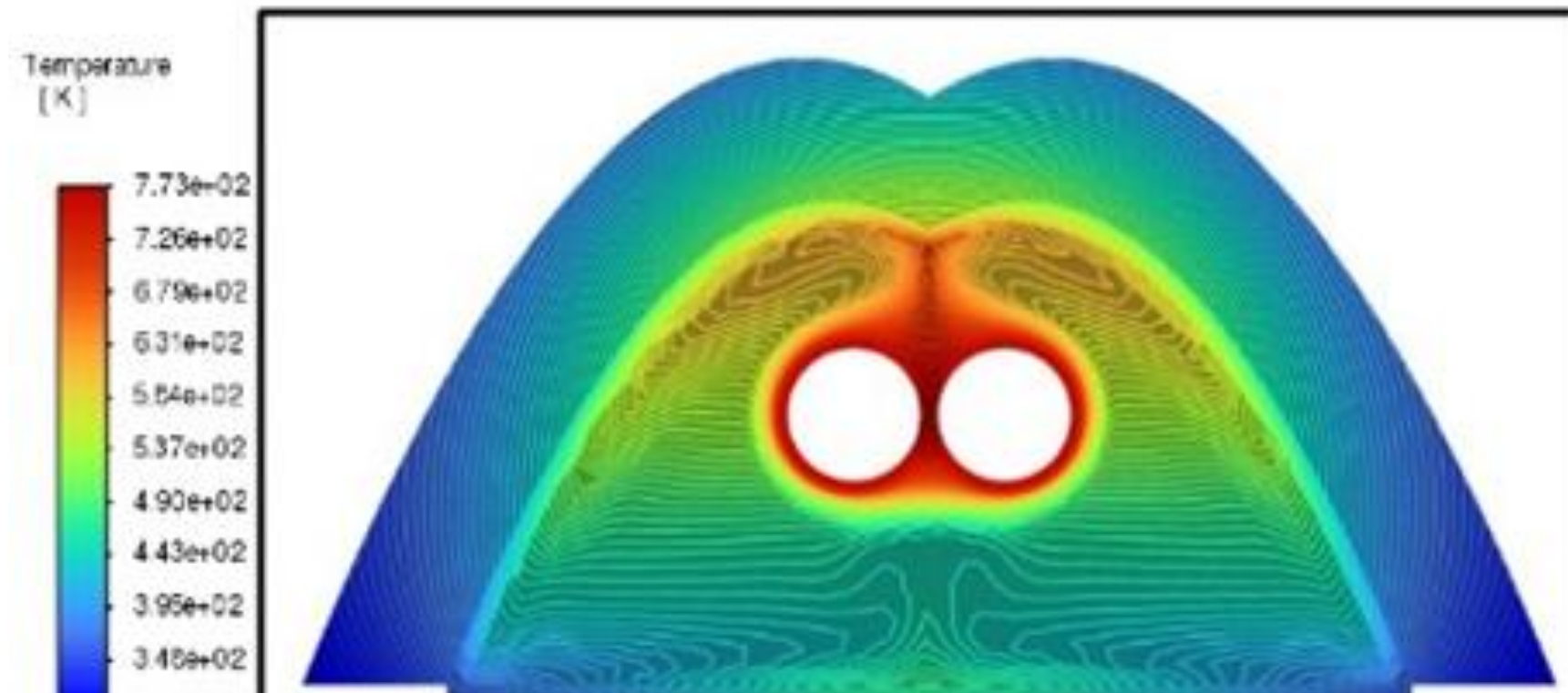
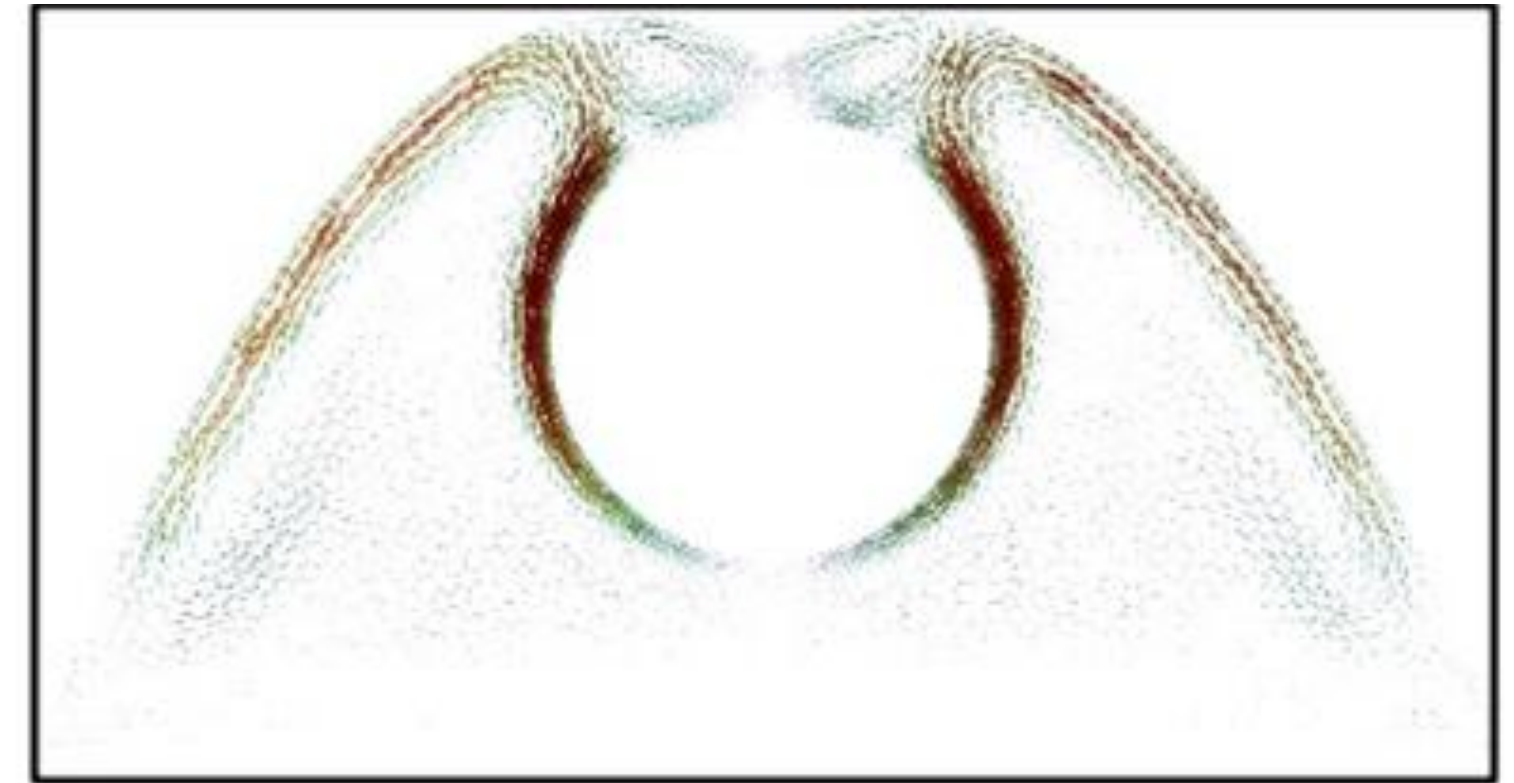
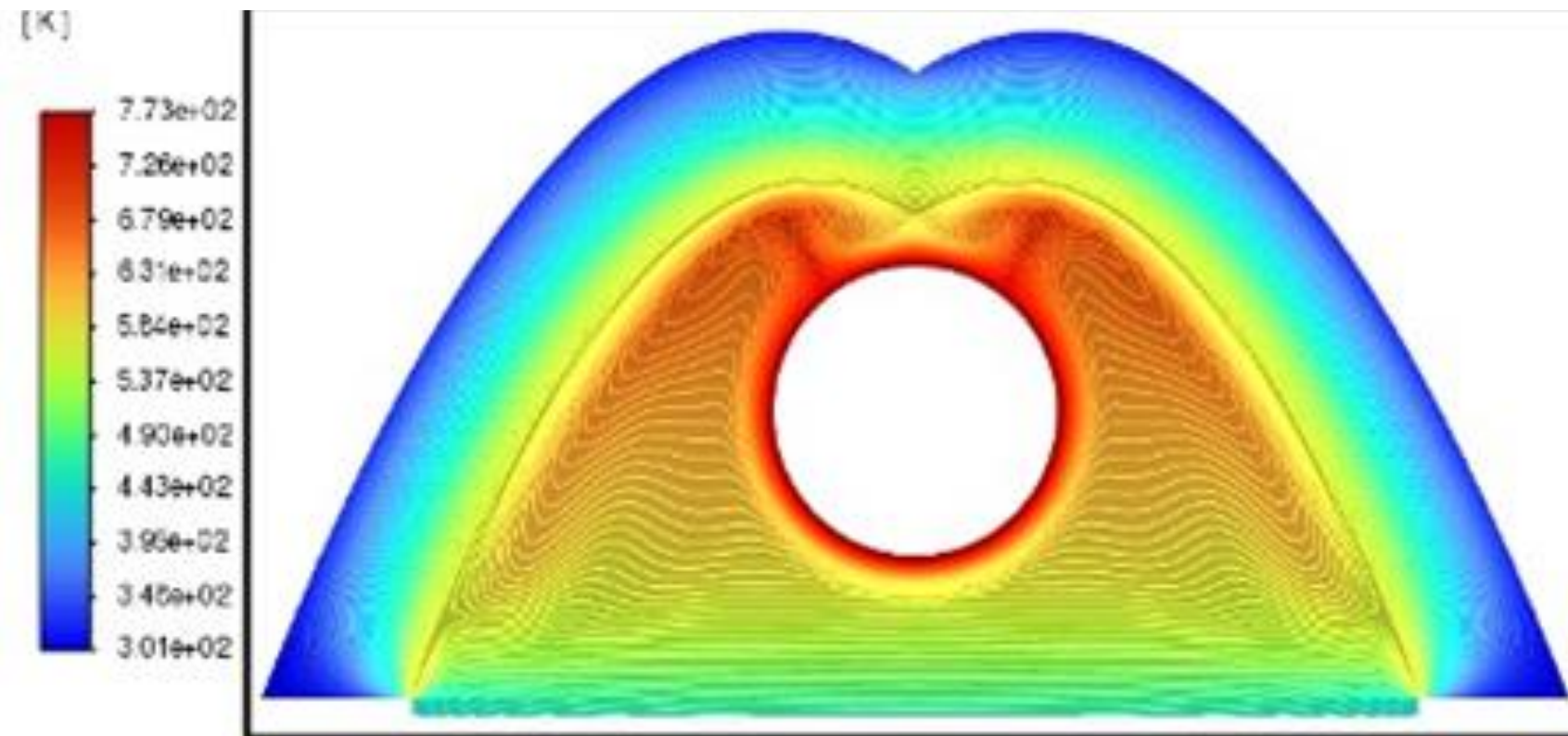
Overall optical efficiency comparison between single-tube and dual-tube designs



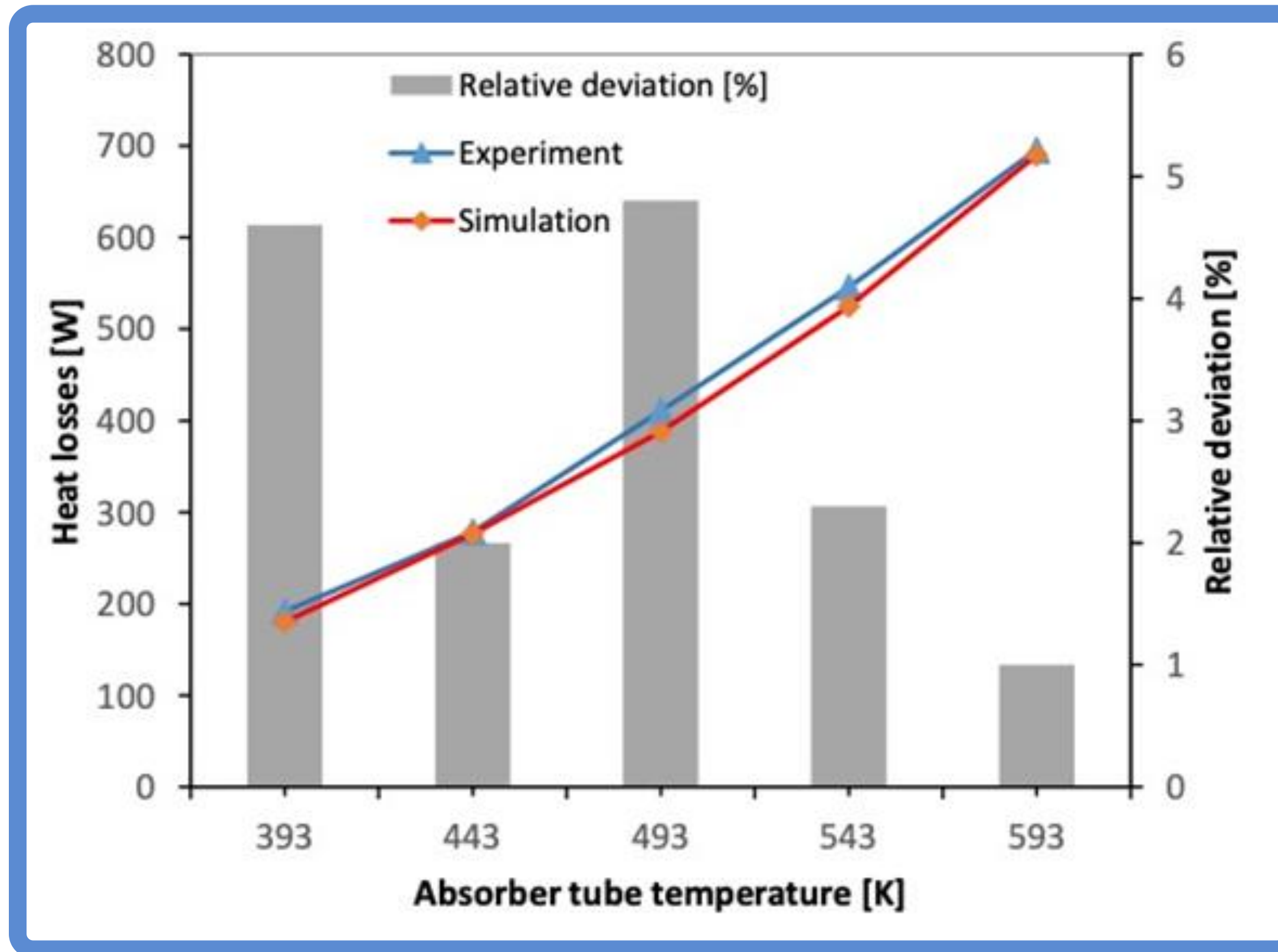
Heat flux absorbed by the glass cover and secondary reflector (a) single tube design, (b) dual-tube design



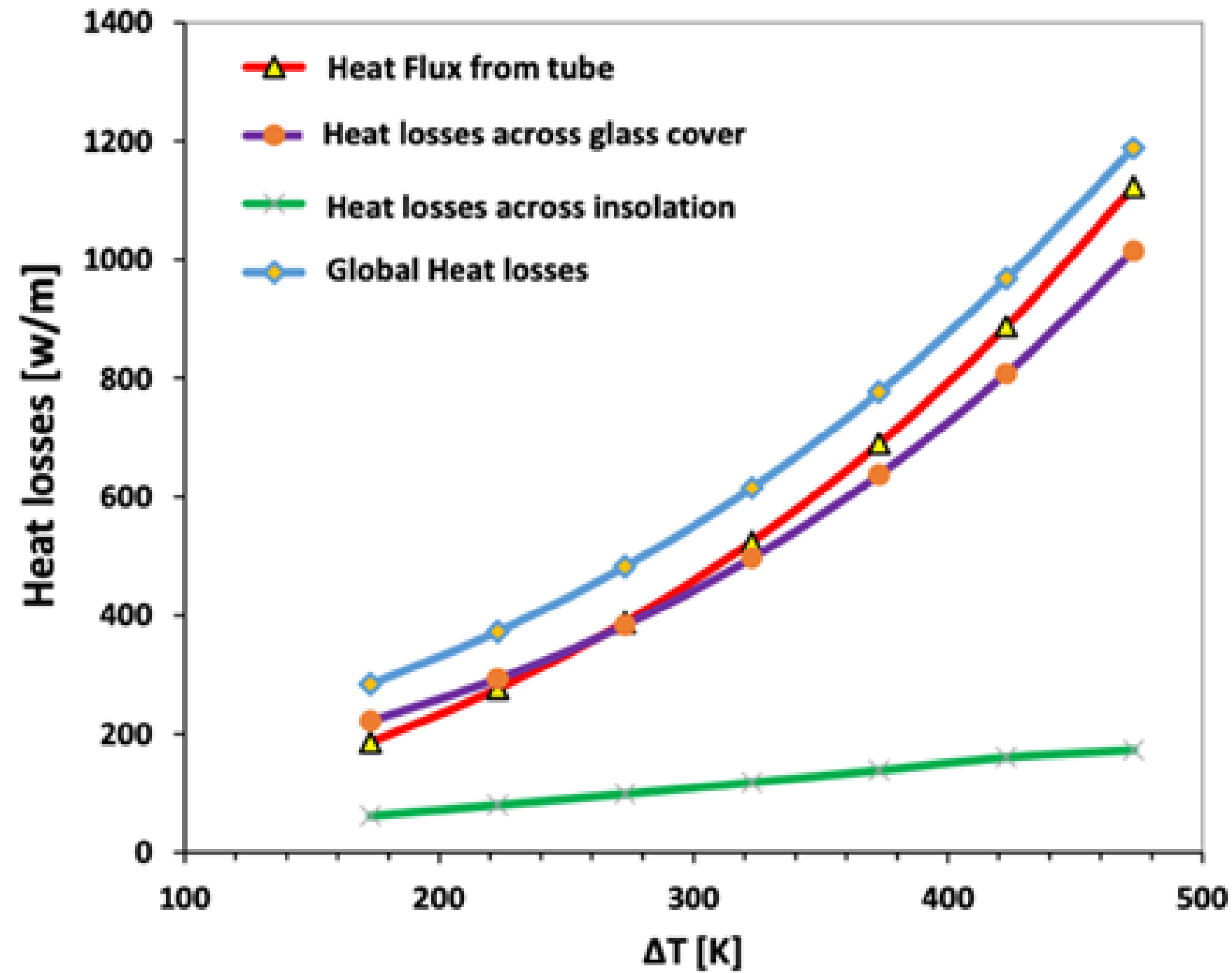
Distribution of temperature within the receiver (a) and velocities fields within the air cavity (b)



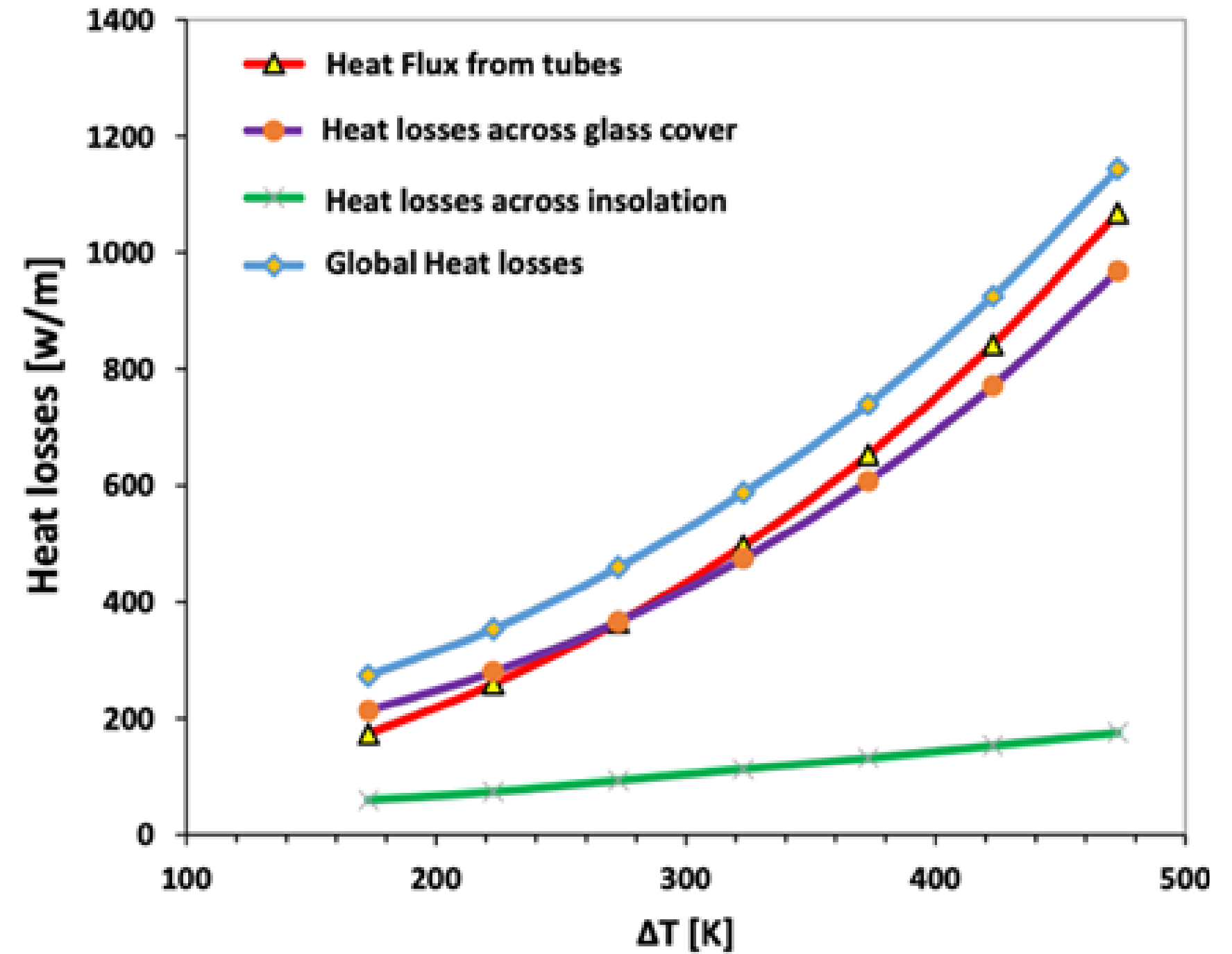
Comparison between experimental and numerical results using the CFD model in terms of global heat losses



Heat flux and heat losses within the receiver cavity: single-tube design (a) and dual-tube design (b)

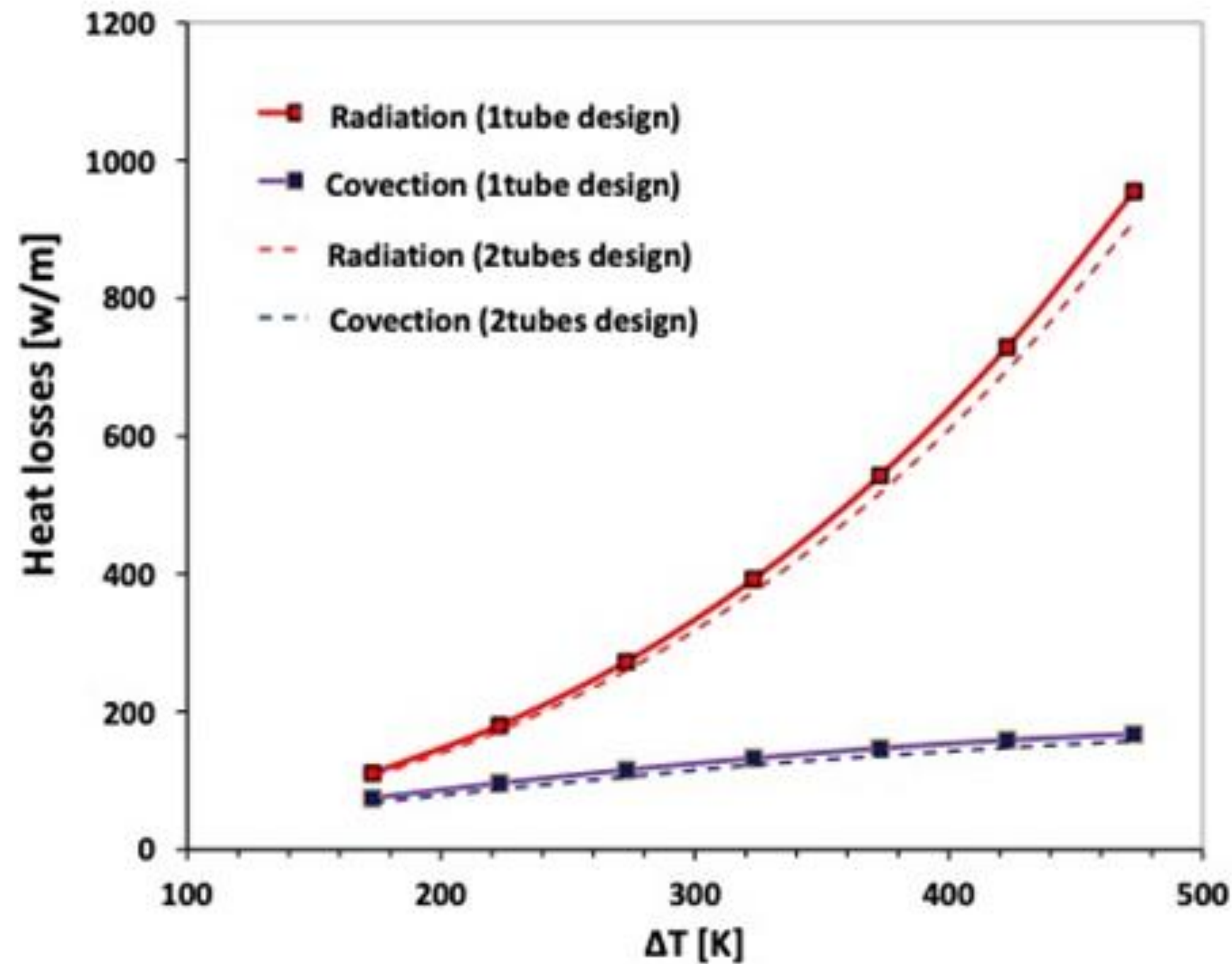


(a)

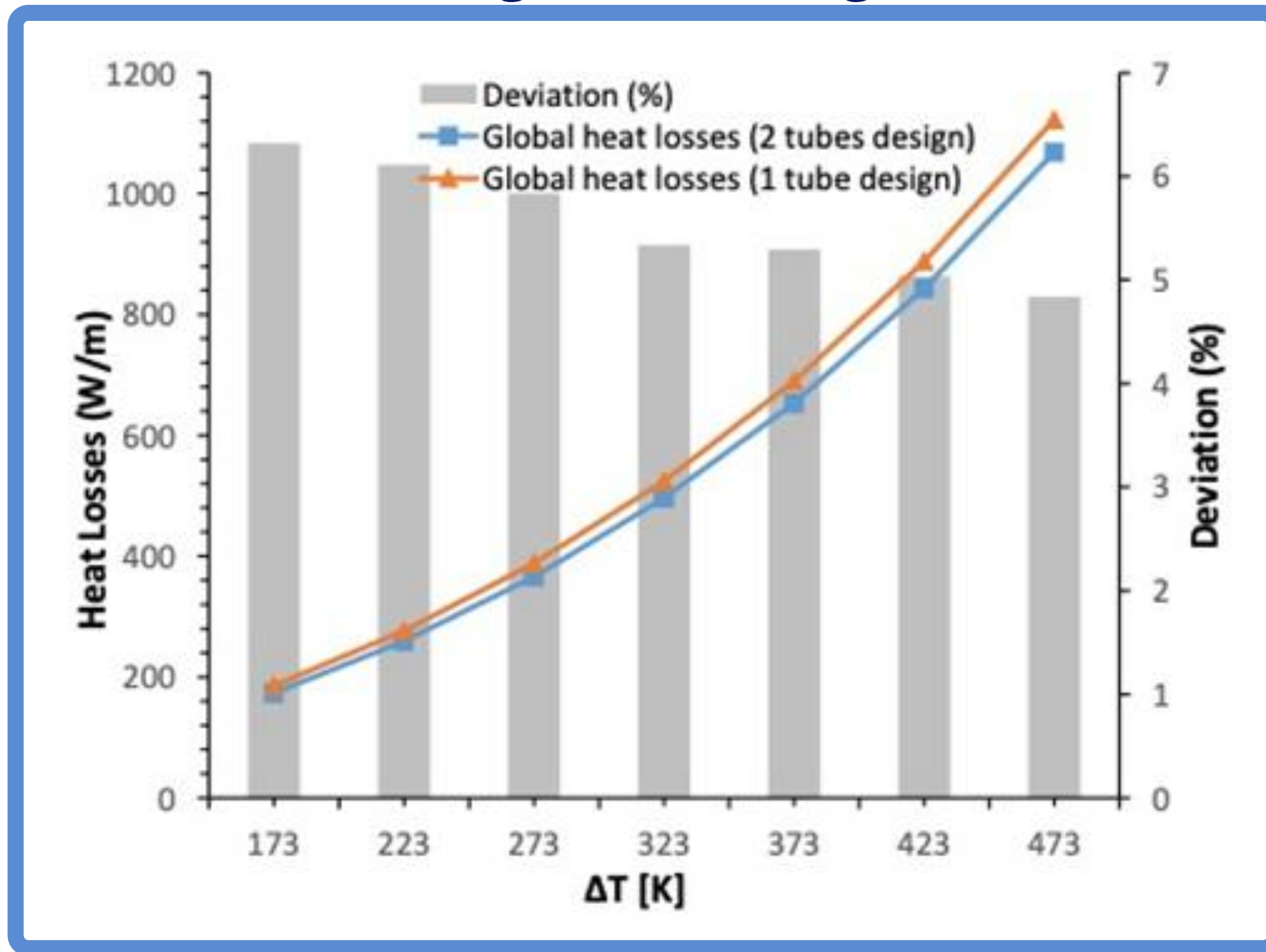


(b)

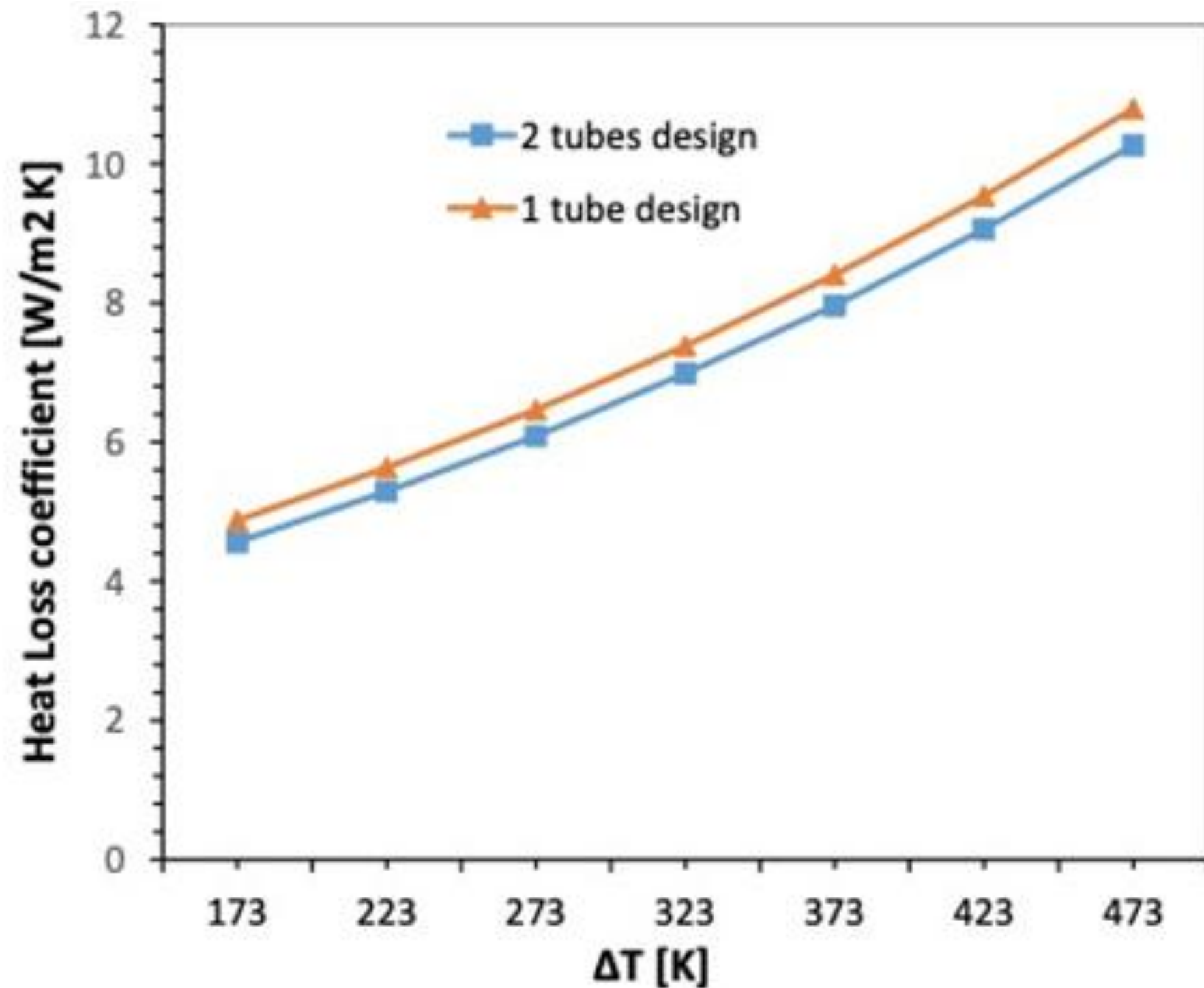
Comparison between the heat losses by convection mode and radiation mode within the receiver cavity



Comparison of global heat losses between the dual-tube and single-tube designs



Overall heat loss coefficient for dual-tube and single-tube designs



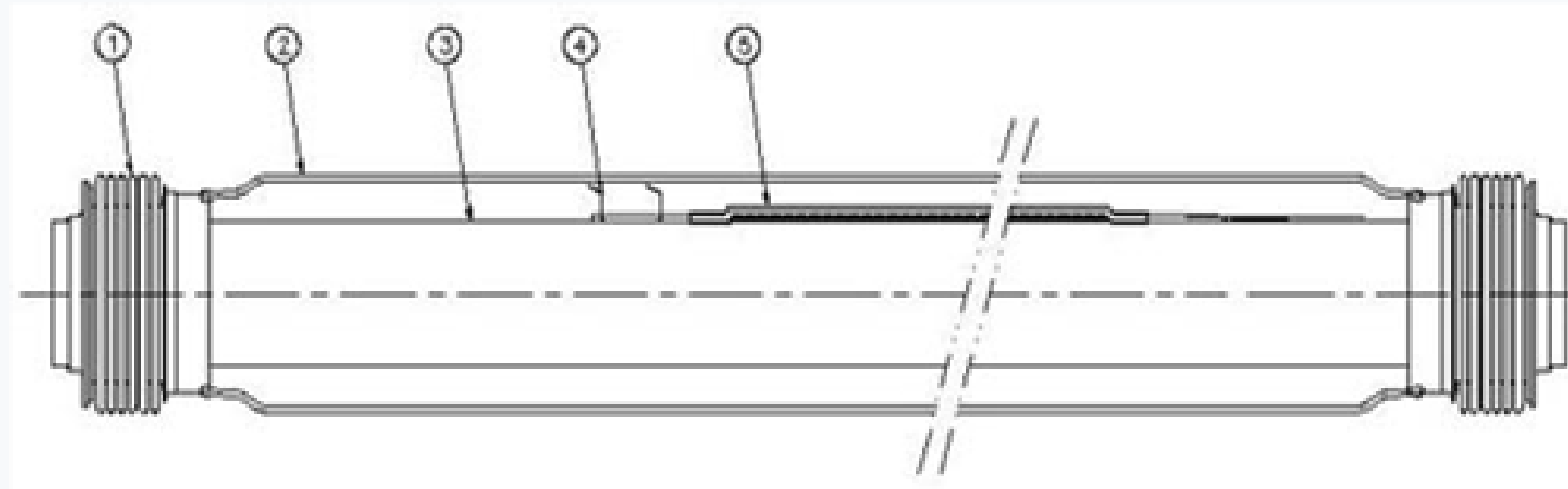


CHAPTER 2

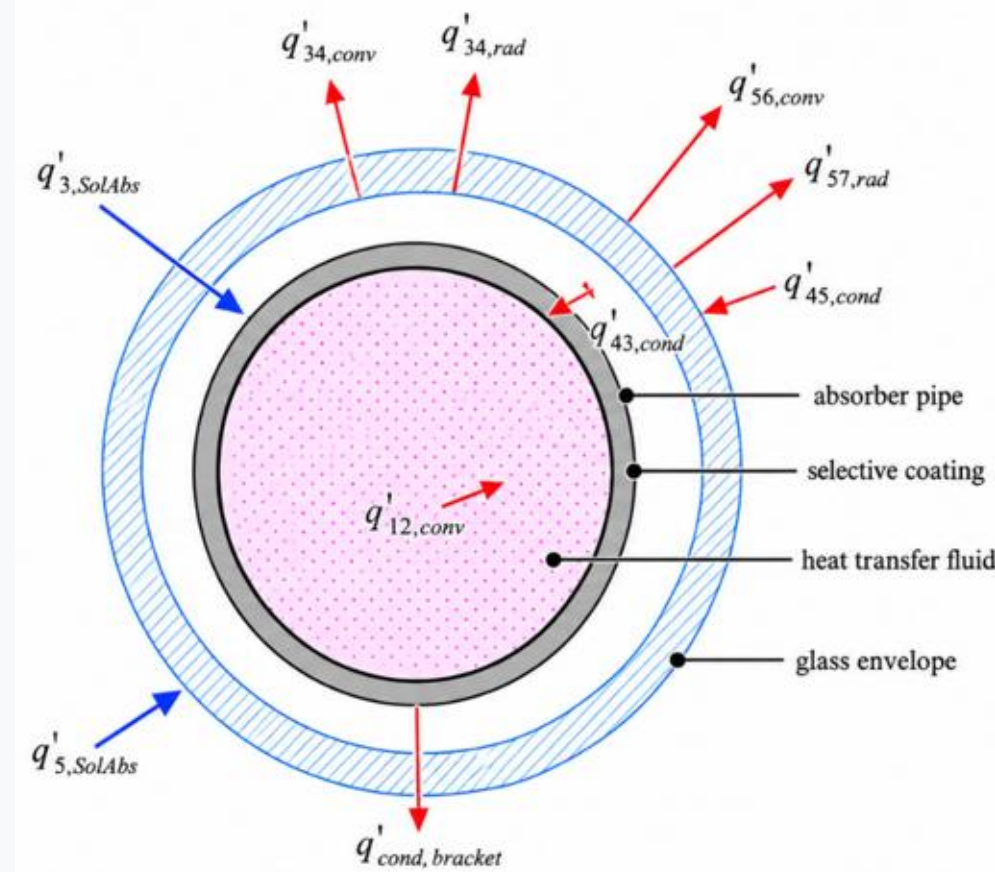
Modelling, validation and thermo-optical enhancement of evacuated
Linear Fresnel receivers



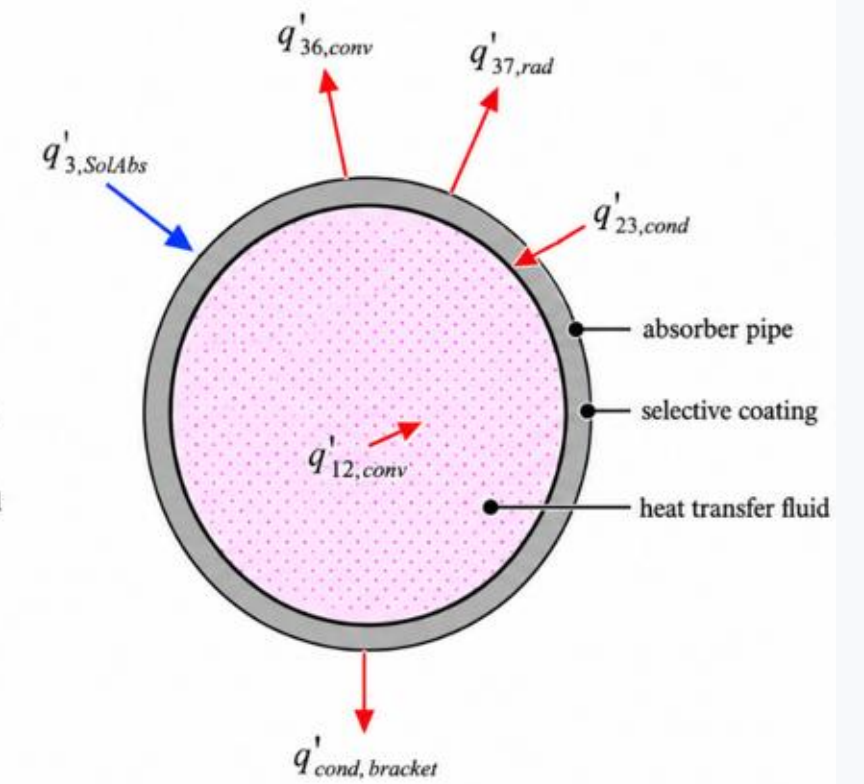
Reference evacuated receiver: PTR70 HCE



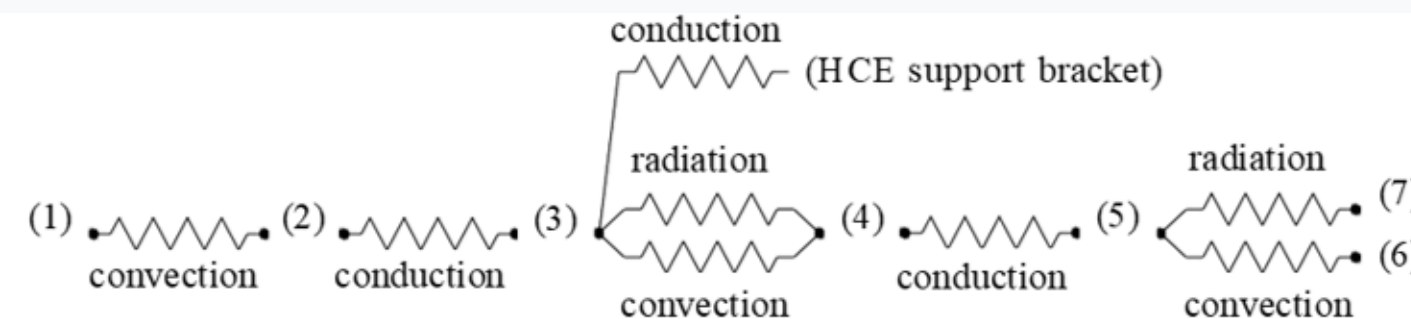
- 1. Bellow
- 2. Glass Tube (Envelope)
- 3. Absorber Tube (Pipe)
- 4. Getter
- 5. Getter Bridge



With Glass Envelope



Without Glass Envelope

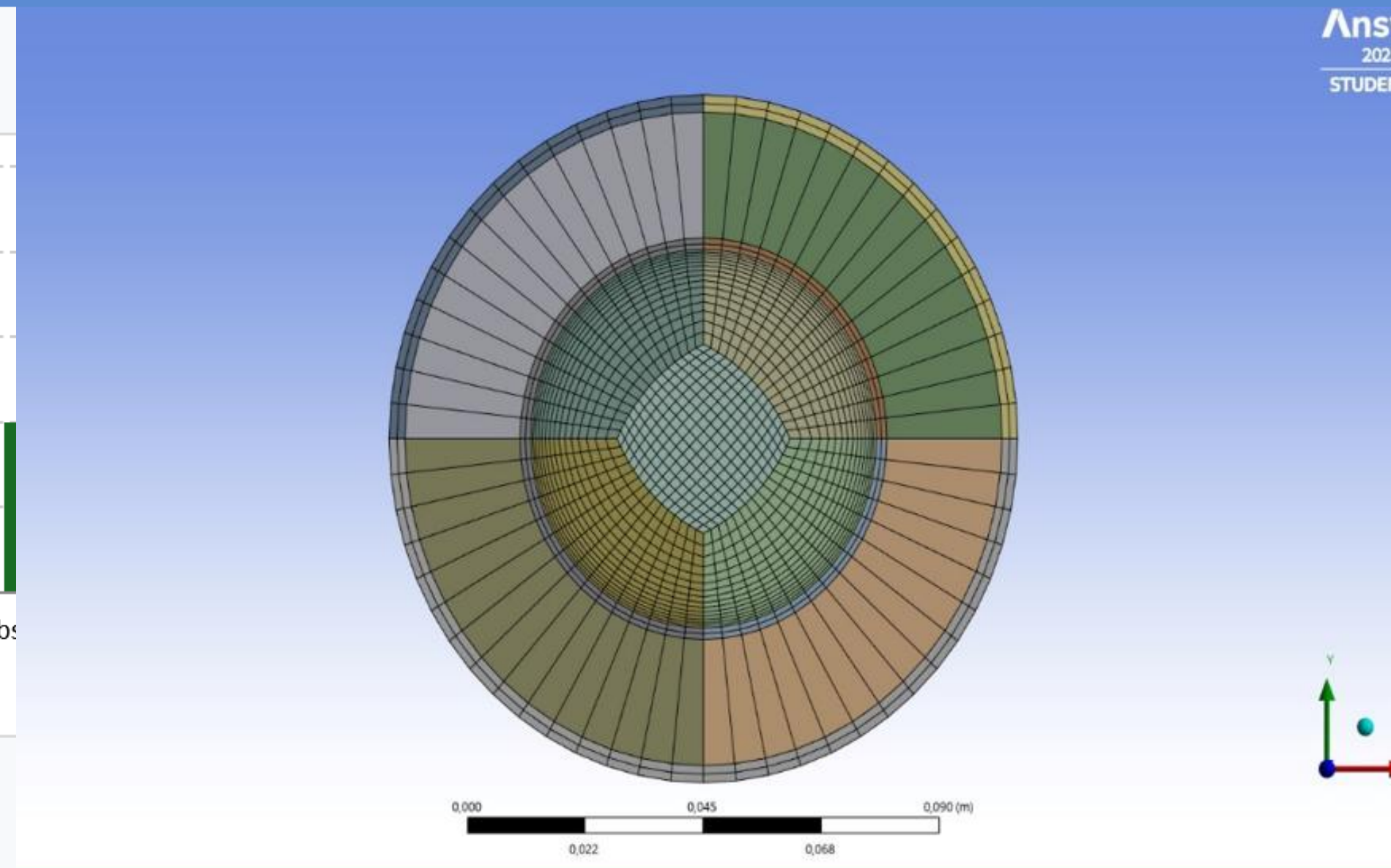
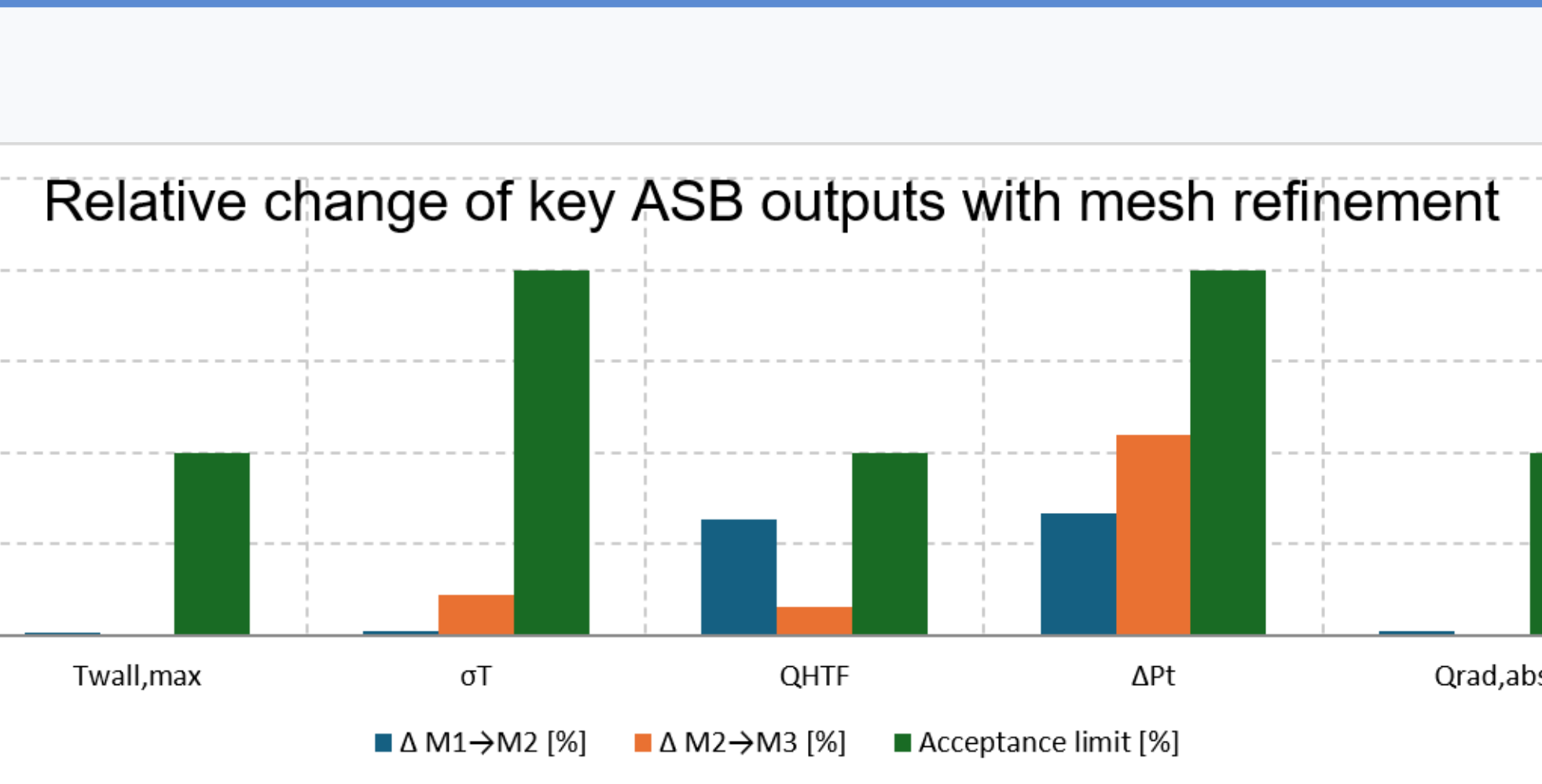


- (1) heat transfer fluid
- (2) absorber inner surface
- (3) absorber outer surface
- (4) glass envelope inner surface

- (5) glass envelope outer surface
- (6) surrounding air
- (7) sky

The vacuum annulus suppresses gas conduction and natural convection.

Numerical reliability: mesh and internal flow checks



Mesh independence and classical correlations verify the numerical setup before benchmark validation.

Thermal CFD model of the PTR70 receiver

Step 4: ANSYS Fluent Setup

1. General

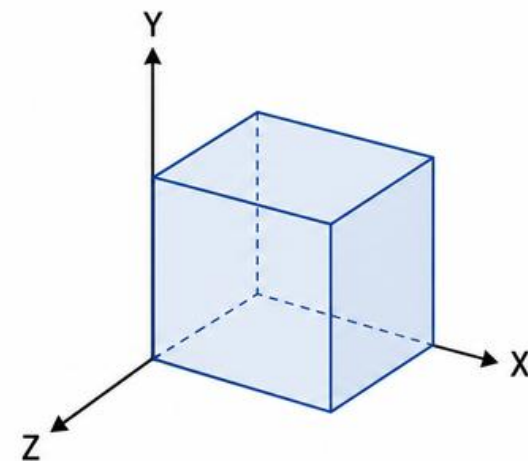
- ✓ 3D
- ✓ Double Precision
- ✓ Pressure-Based Solver
- ✓ Steady State
- ✓ Absolute velocity formulation

↓ Enable gravity, for example:

$$g_y = -9.81 \text{ m/s}^2$$



depending on the orientation of the model.



Therminol VP-1 Thermophysical Properties

Temperature-dependent correlations used in the CFD model



1. Specific heat capacity, $c_{p,f}$

$$c_{p,f} = 2.125 \times 10^3 - 11.017T + 0.049862T^2 - 7.7663 \times 10^{-5}T^3 + 4.394 \times 10^{-8}T^4$$



2. Density, ρ_f

$$\rho_f = 1.4386 \times 10^3 - 1.8711T + 2.737 \times 10^{-3}T^2 - 2.3793 \times 10^{-6}T^3$$



3. Thermal conductivity, λ_f

$$\lambda_f = 0.14644 + 2.0353 \times 10^{-5}T - 1.9367 \times 10^{-7}T^2 + 1.0614 \times 10^{-11}T^3$$



4. Dynamic viscosity, μ_f

$$\mu_f = 23.165 - 0.1476T + 3.617 \times 10^{-4}T^2 - 3.9844 \times 10^{-7}T^3 + 1.6543 \times 10^{-10}T^4$$



Validity range:

$$373.15 \leq T \leq 698.15 \text{ K}$$



T is the fluid temperature in K; $c_{p,f}$ is in $\text{J kg}^{-1} \text{K}^{-1}$, ρ_f is in kg m^{-3} , and λ_f is in $\text{W m}^{-1} \text{K}^{-1}$.

2. Models

Enable:



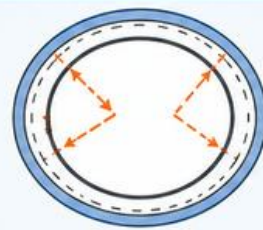
1 Energy Equation



2 k - ω SST turbulence model for Therminol VP-1 flow



3 Surface-to-Surface Radiation (S2S)



The S2S radiation model is appropriate because thermal radiation is exchanged between the outer absorber surface and the inner glass surface, while the evacuated annulus acts as a non-participating medium.

- Outer absorber surface
- Inner glass surface
- - - Evacuated annulus (non-participating medium)

3. Glass

According to the referenced article



$$k_g = 1.2 \text{ W/(m}\cdot\text{K)}$$

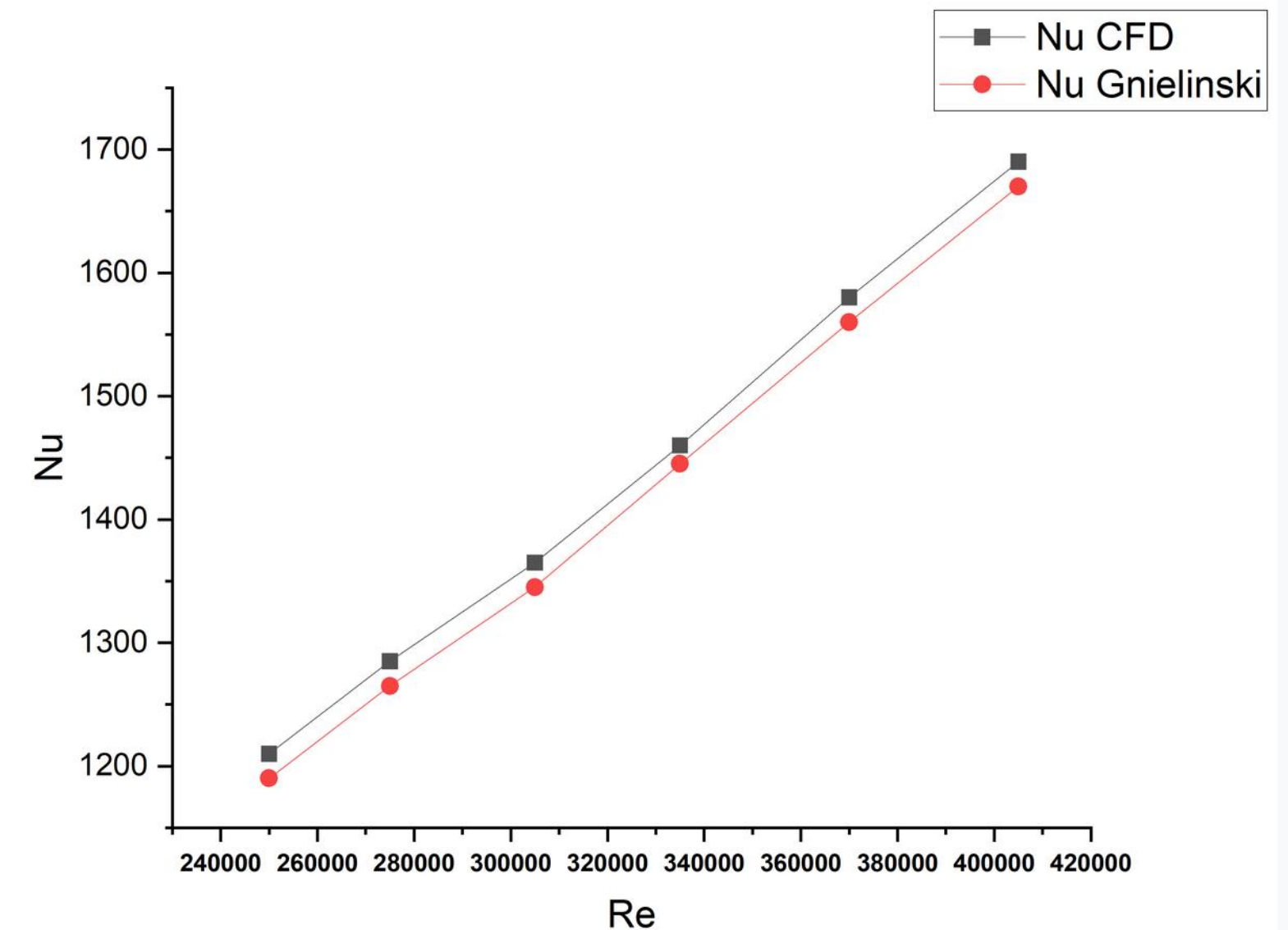
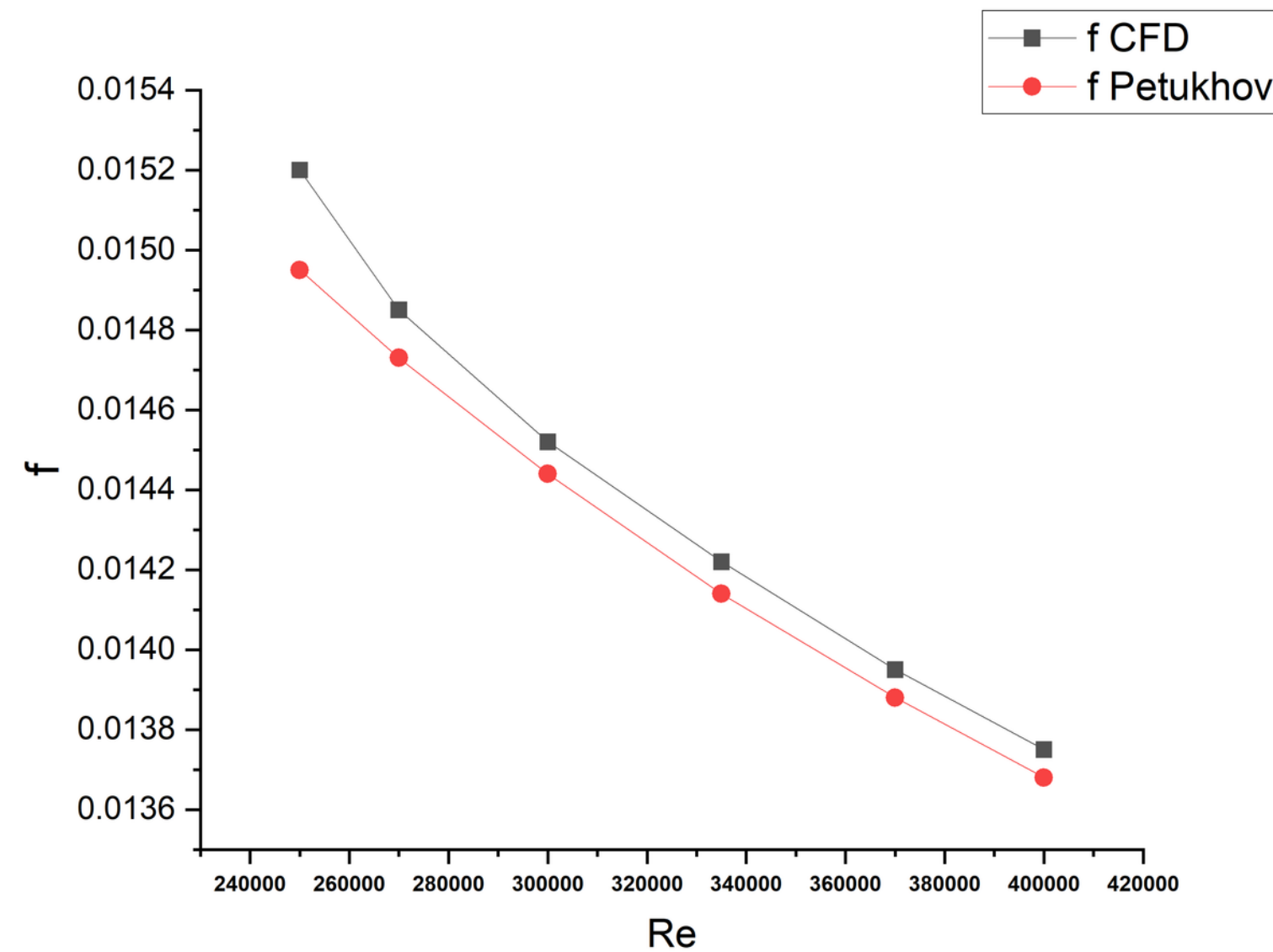


$$\varepsilon_g = 0.86$$



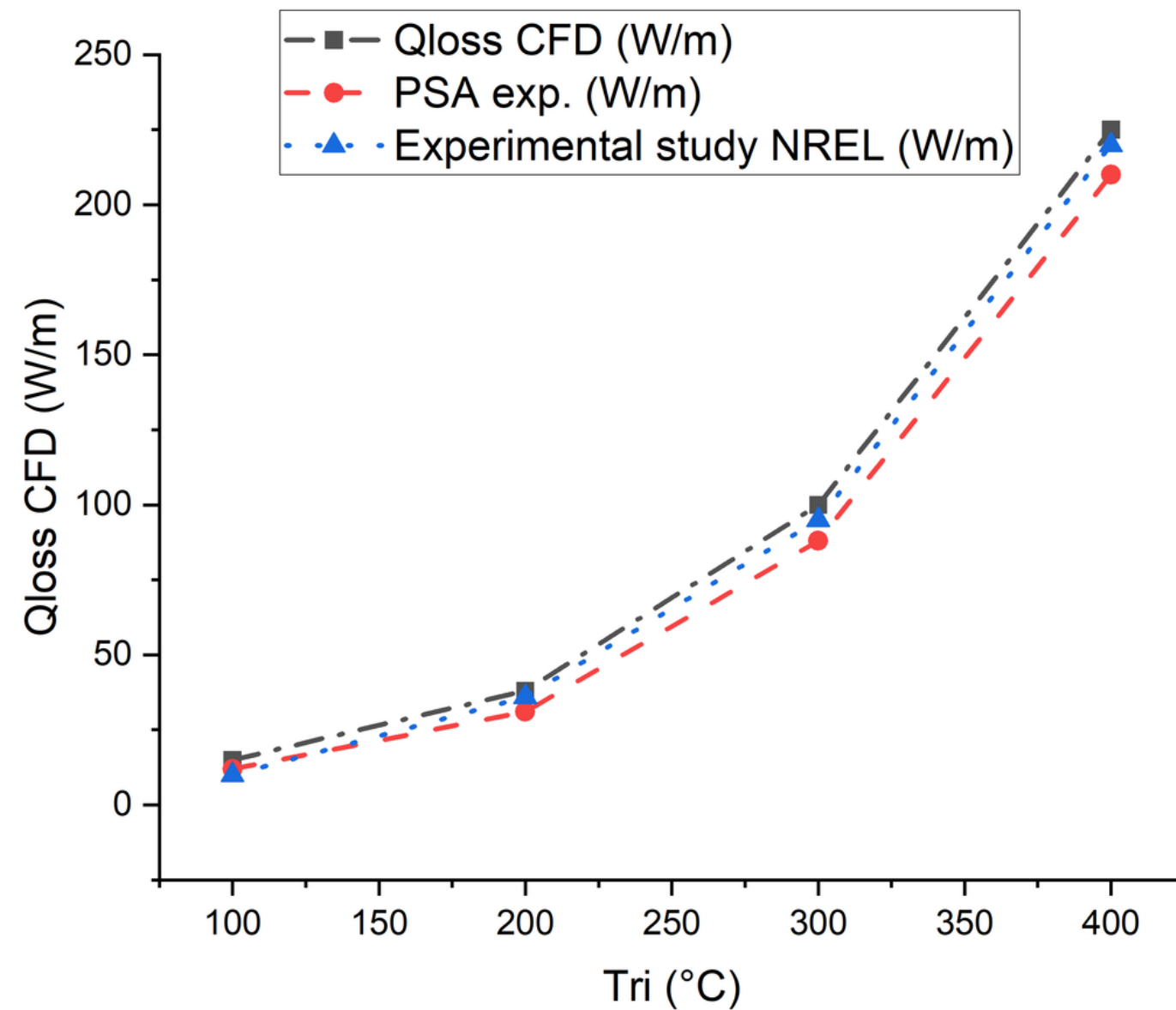
This model is built to reproduce the receiver heat-transfer behaviour.

Numerical reliability: mesh and internal flow checks



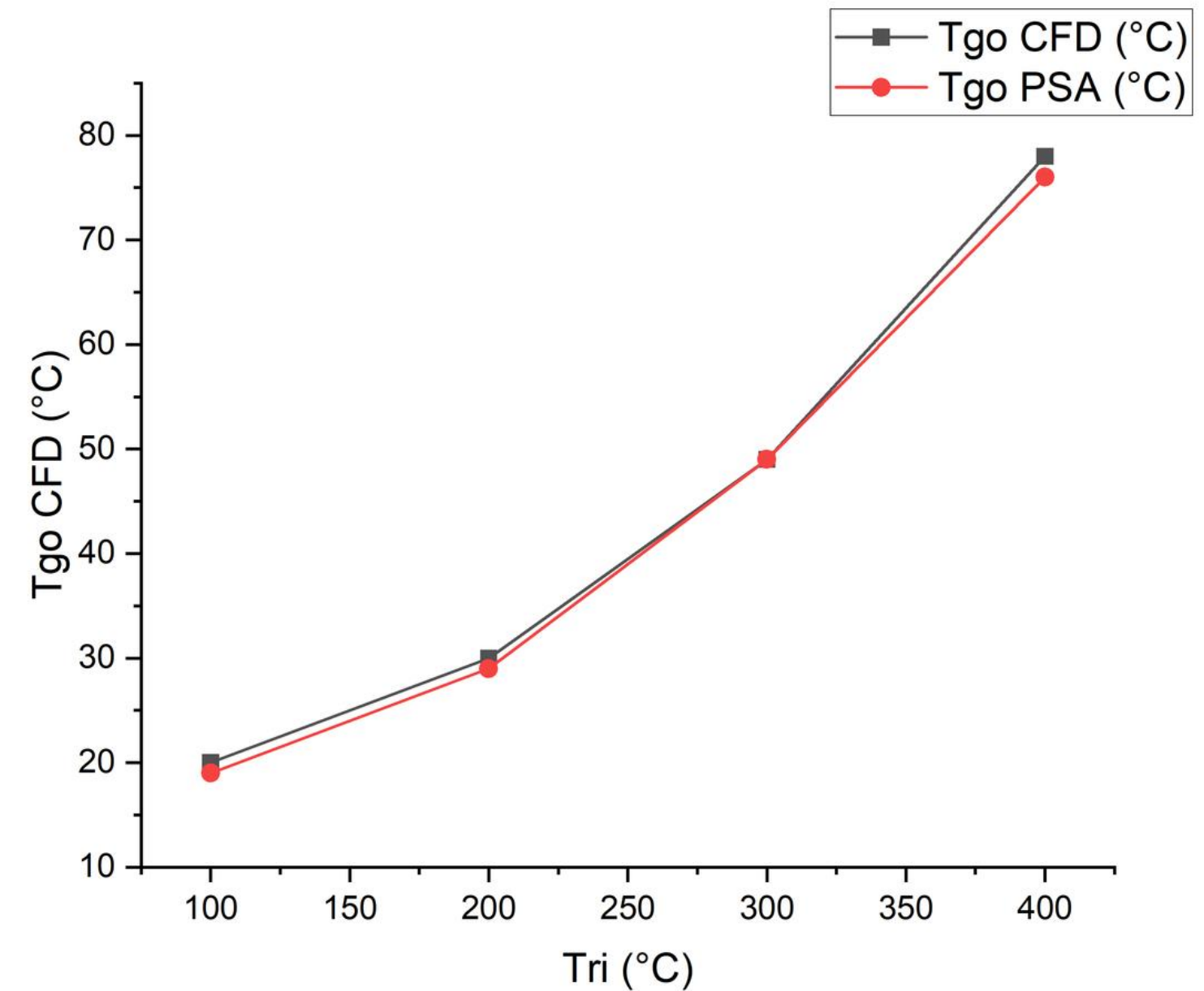
Mesh independence and classical correlations verify the numerical setup before benchmark validation.

Benchmark validation with NREL and PSA data



5.1%

mean deviation in heat-loss prediction



3.0%

mean deviation in glass-envelope temperature

What validation enables

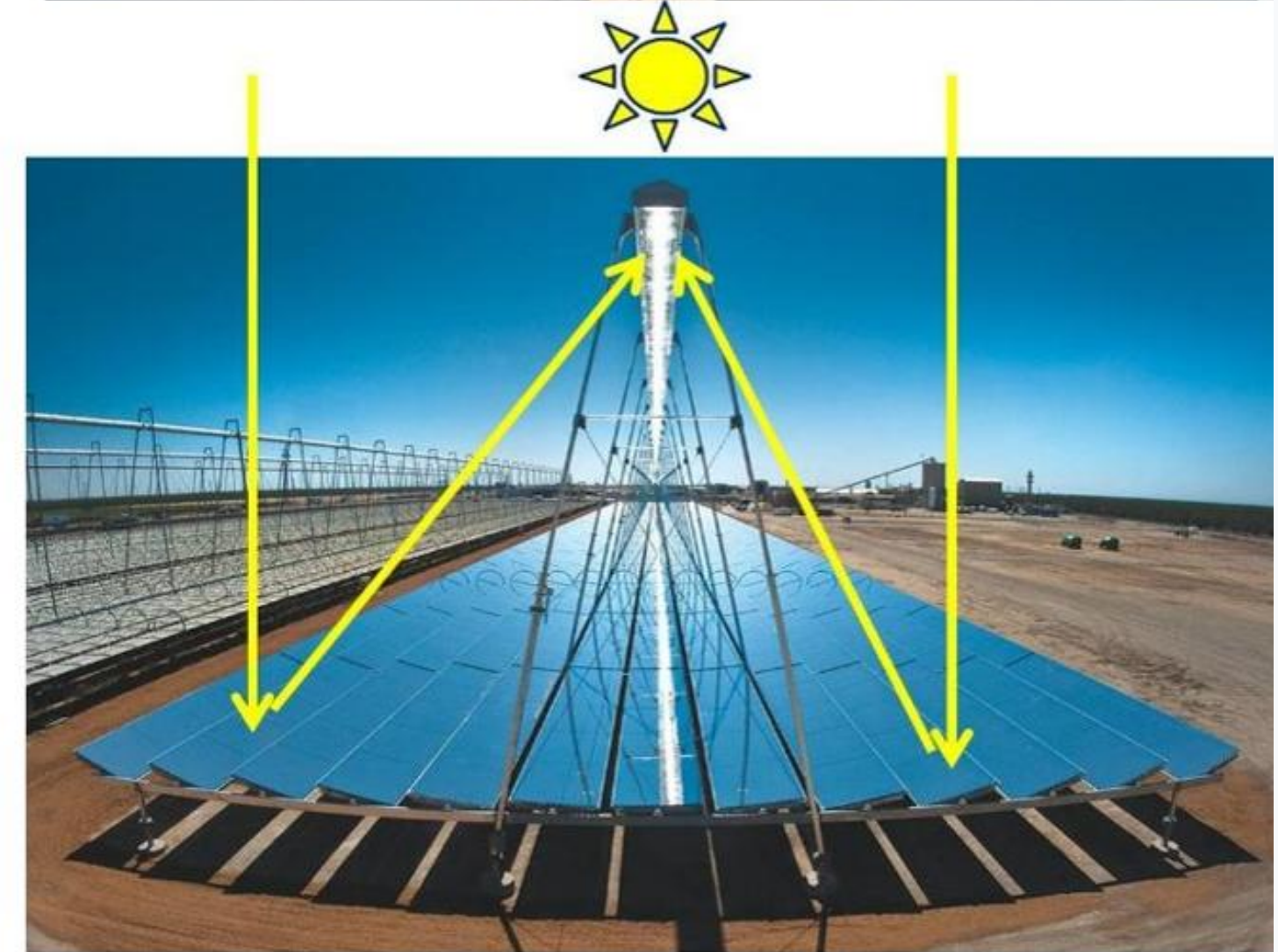
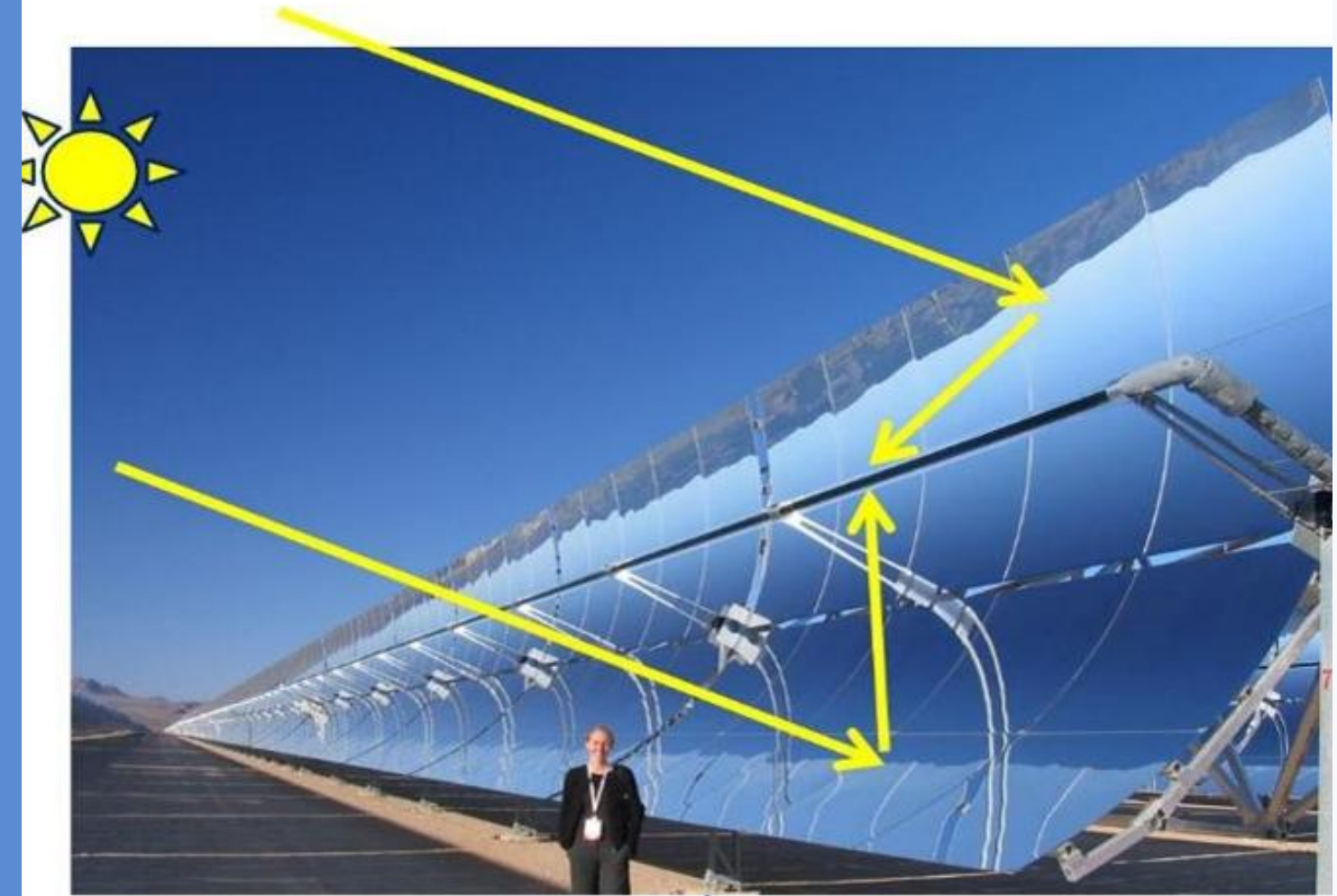
Validation is performed under PTC benchmark conditions

The validated thermal model represents the PTR70 receiver itself

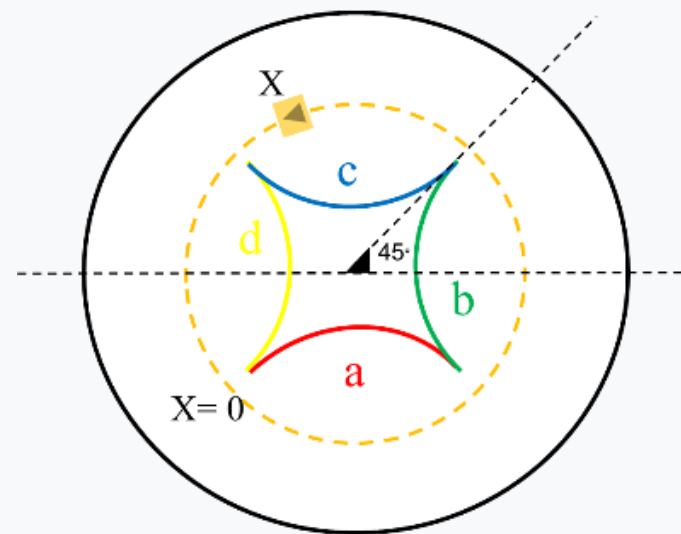
For LFR applications, replace the incident solar-flux map and operating conditions

The same receiver framework predicts temperature, useful heat, and heat losses

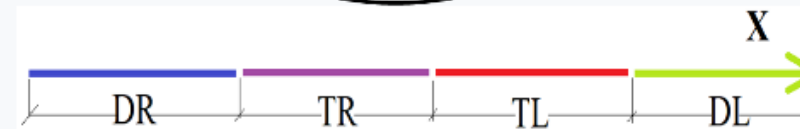
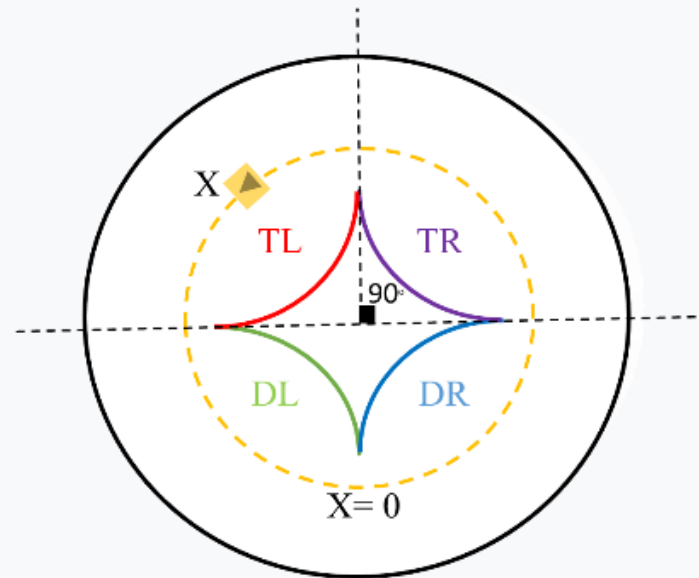
PTR70 validation becomes the thermal foundation for the evacuated-receiver part of the thesis.



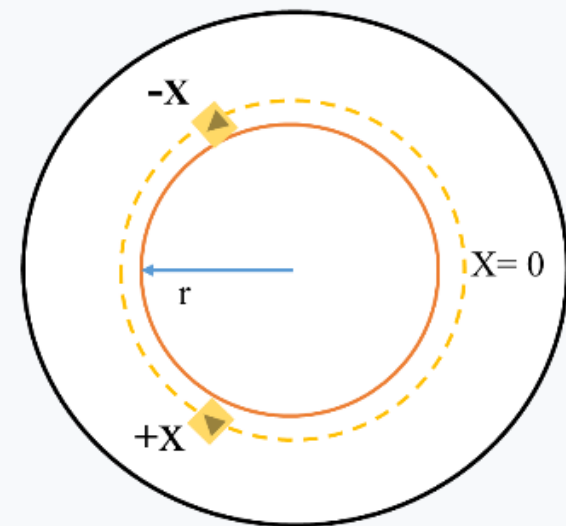
Next challenge: non-uniform flux on circular absorbers



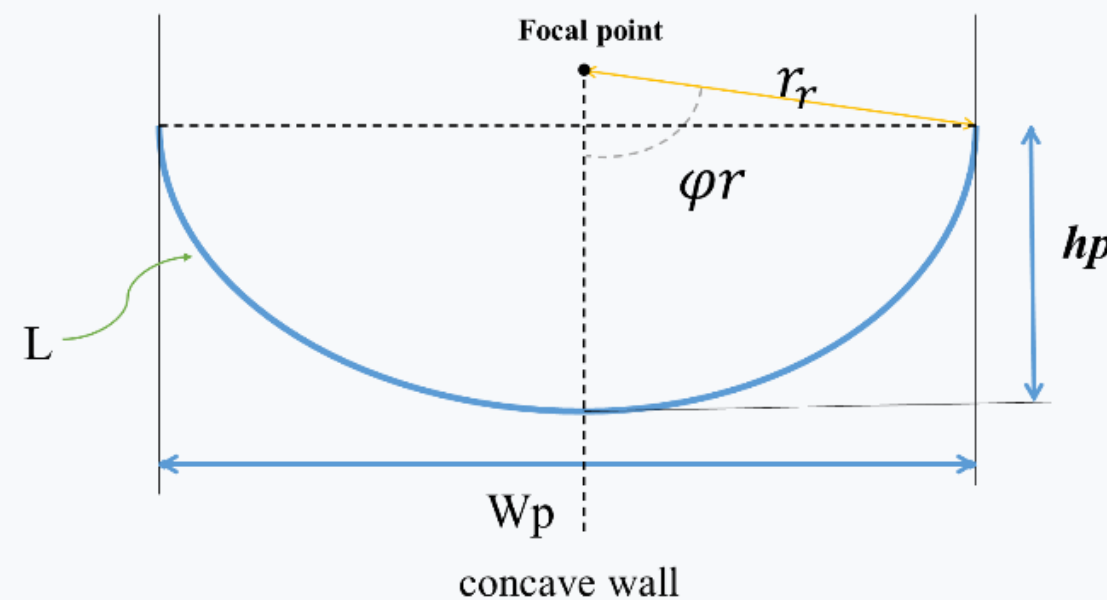
CWD 45



CWD 90



ASB



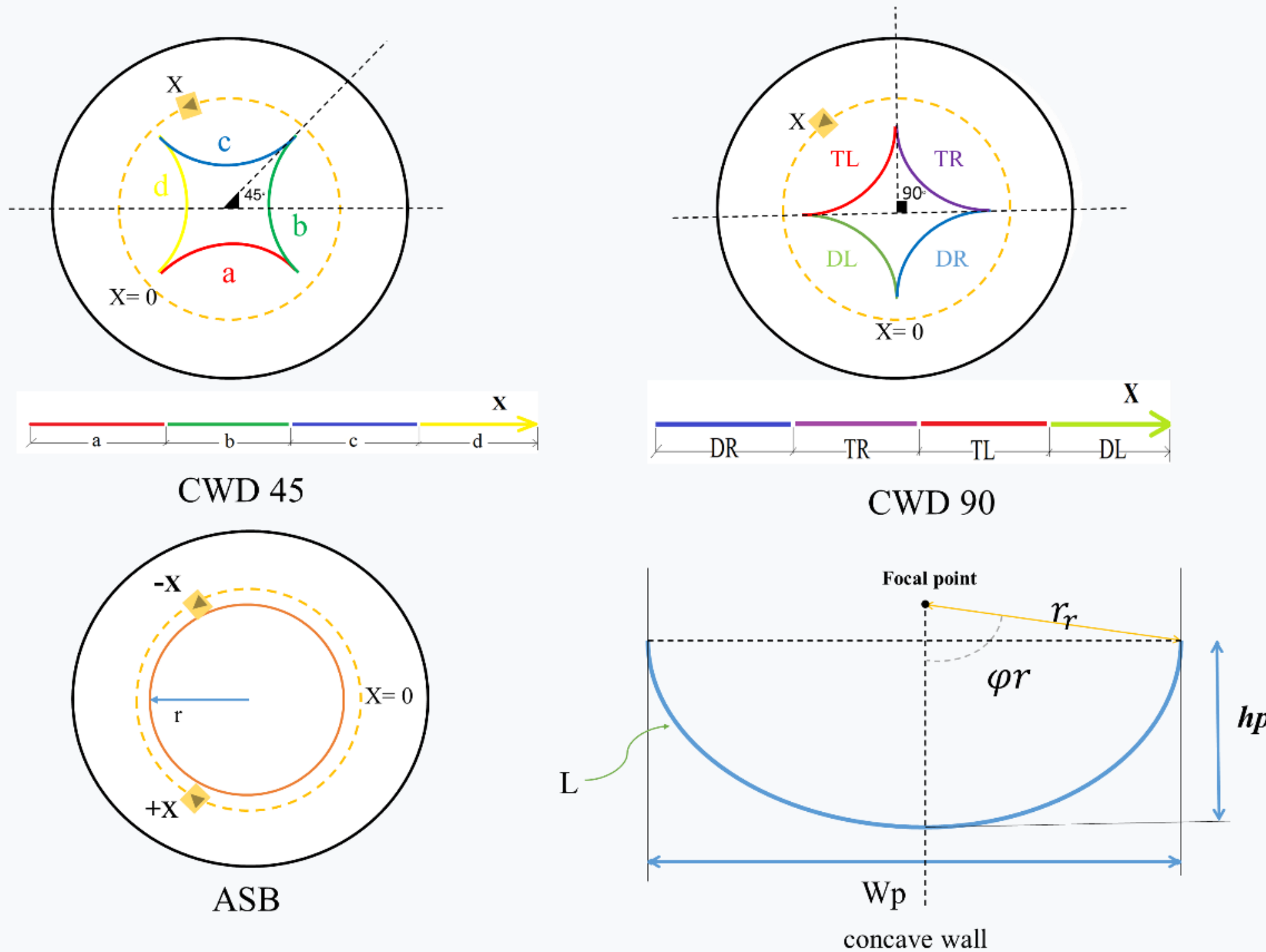
Conventional ASB absorbers receive strongly non-uniform circumferential flux

Local flux peaks can produce hot spots and uneven thermal loading

Absorber geometry becomes a passive optical-design variable

Improving flux uniformity is a durability-oriented receiver-design goal.

Novel concave-wall absorber geometries



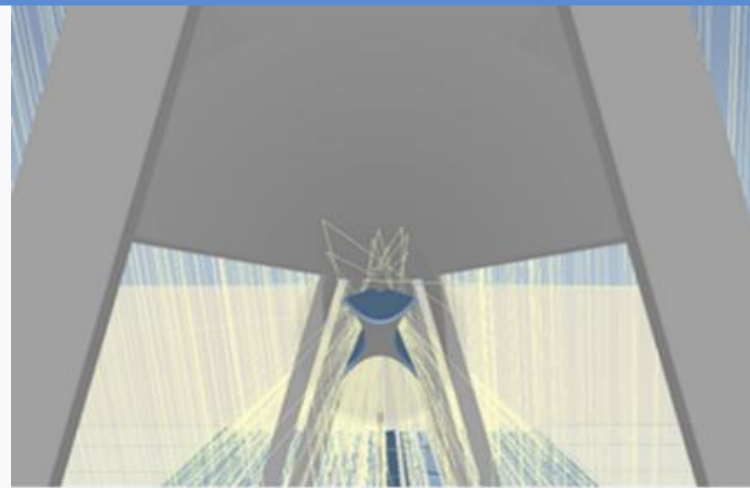
ASB: conventional circular absorber

CWD-45: four-wall concave geometry, 45° orientation

CWD-90: four-wall concave geometry, 90° orientation

The optical question: can geometry divide and redistribute concentrated radiation?

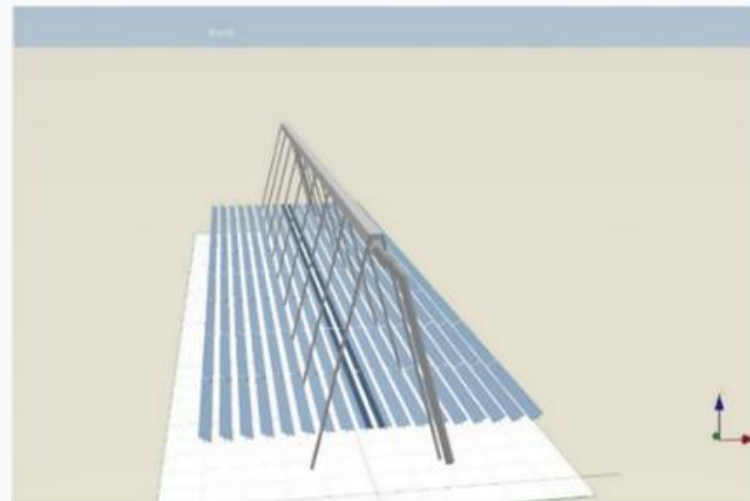
Optical model: LFR1832 and Tonatiuh++



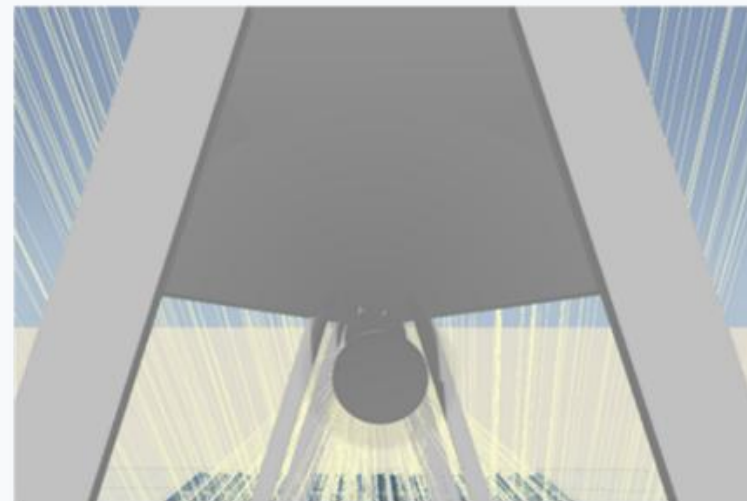
(b)



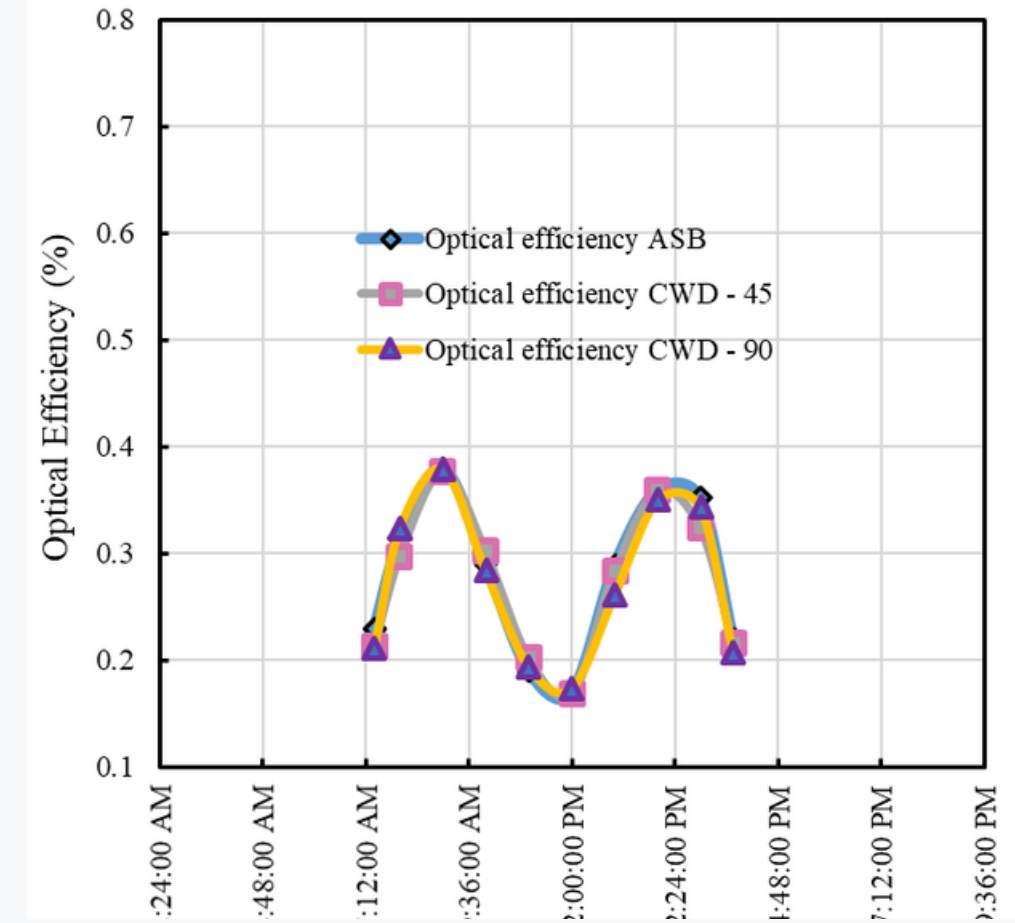
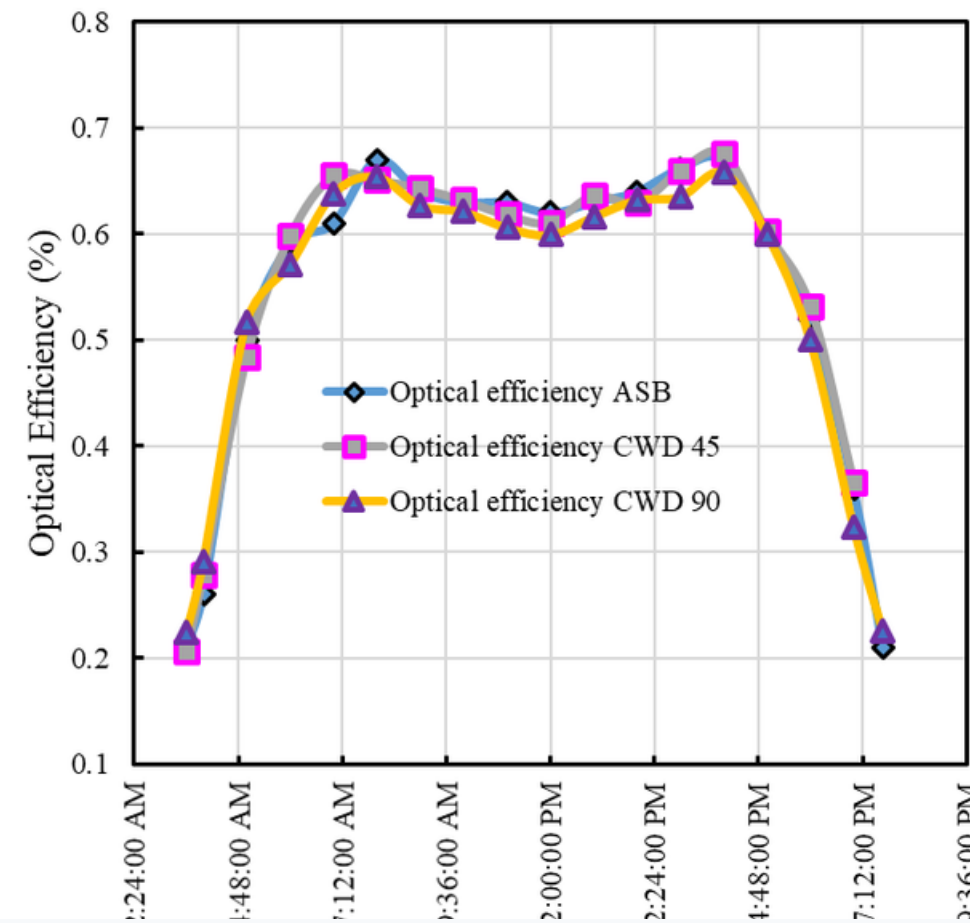
(c)



(a)



(d)



The optical study tests absorber designs under realistic locations and seasons.

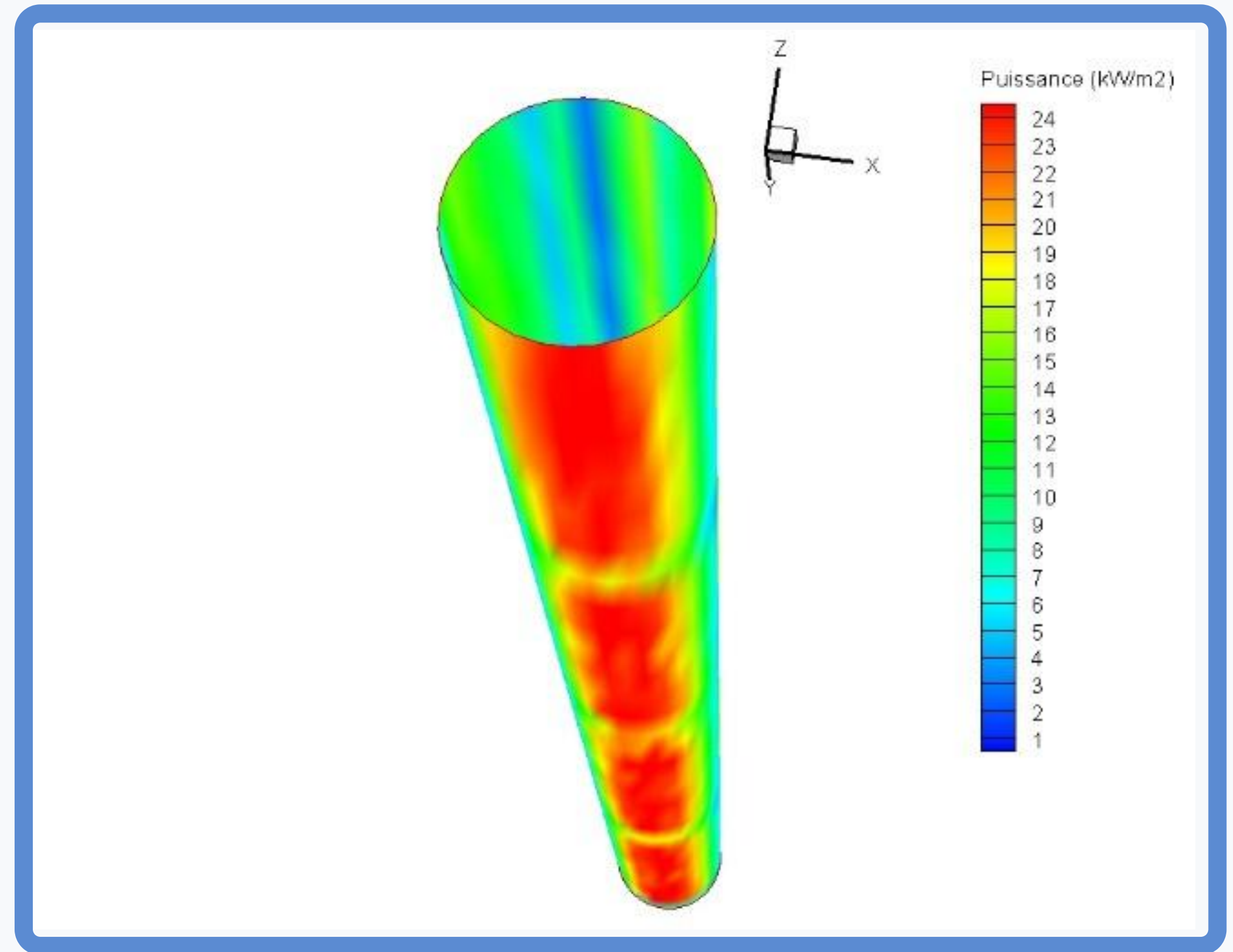
Performance metrics: not only efficiency

Daily optical efficiency: how much energy is intercepted

Peak local flux: where hot spots may form

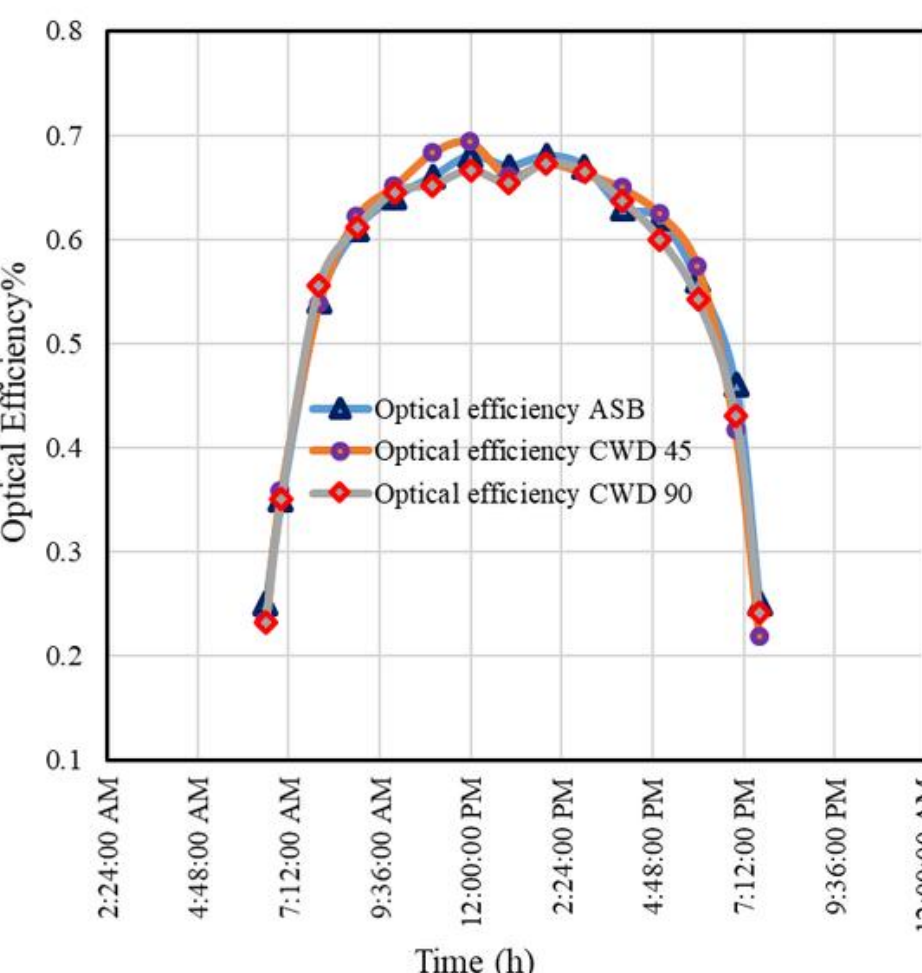
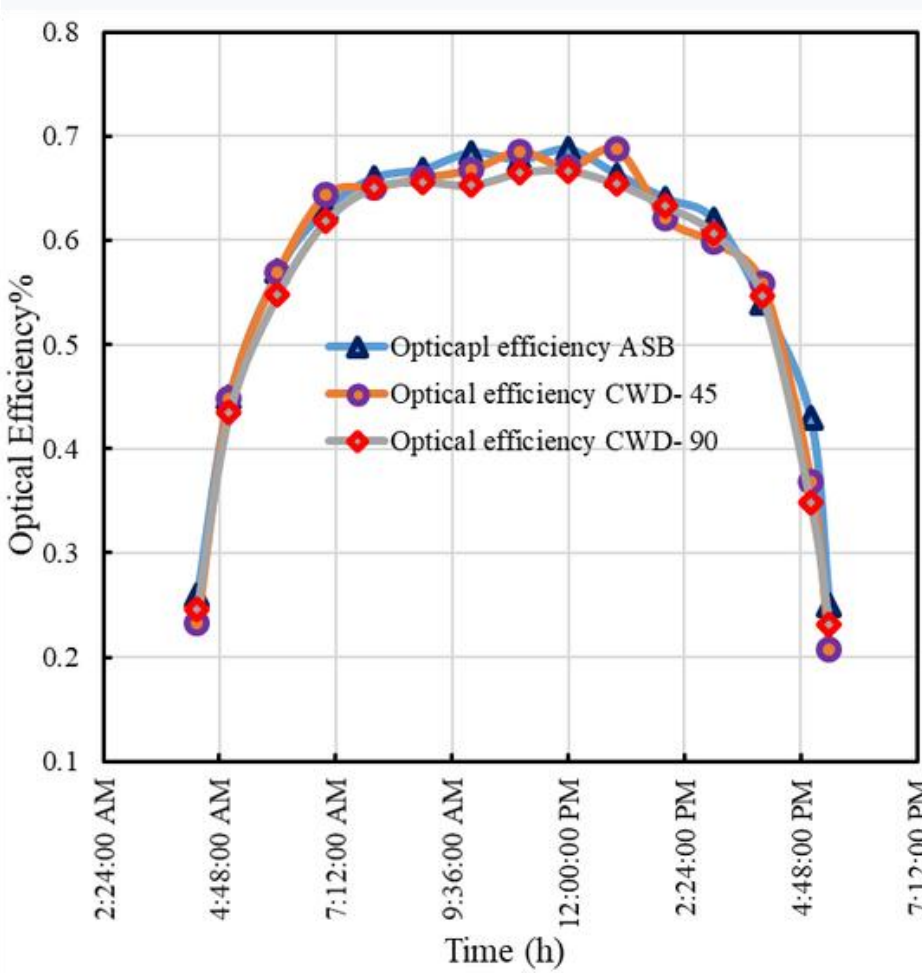
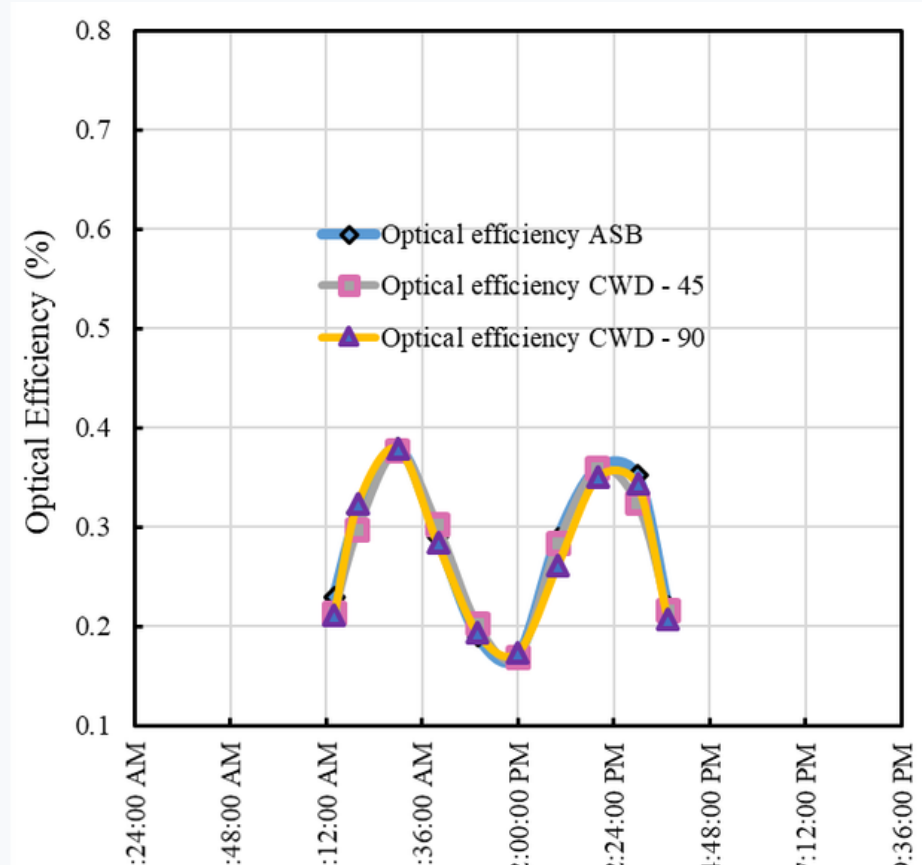
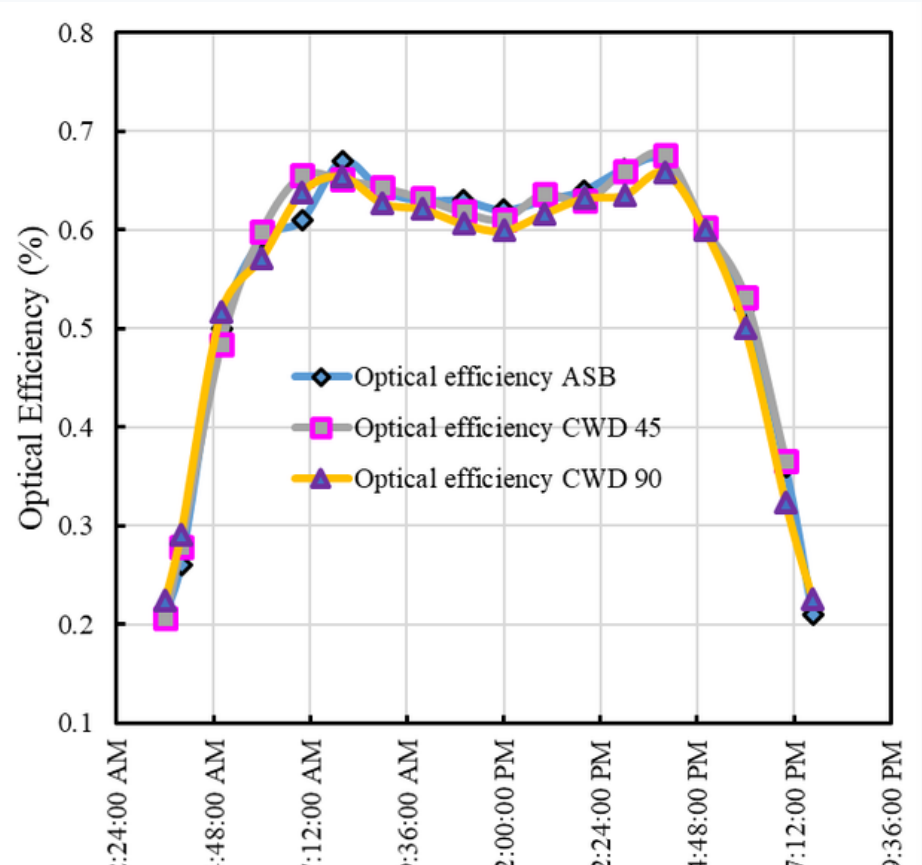
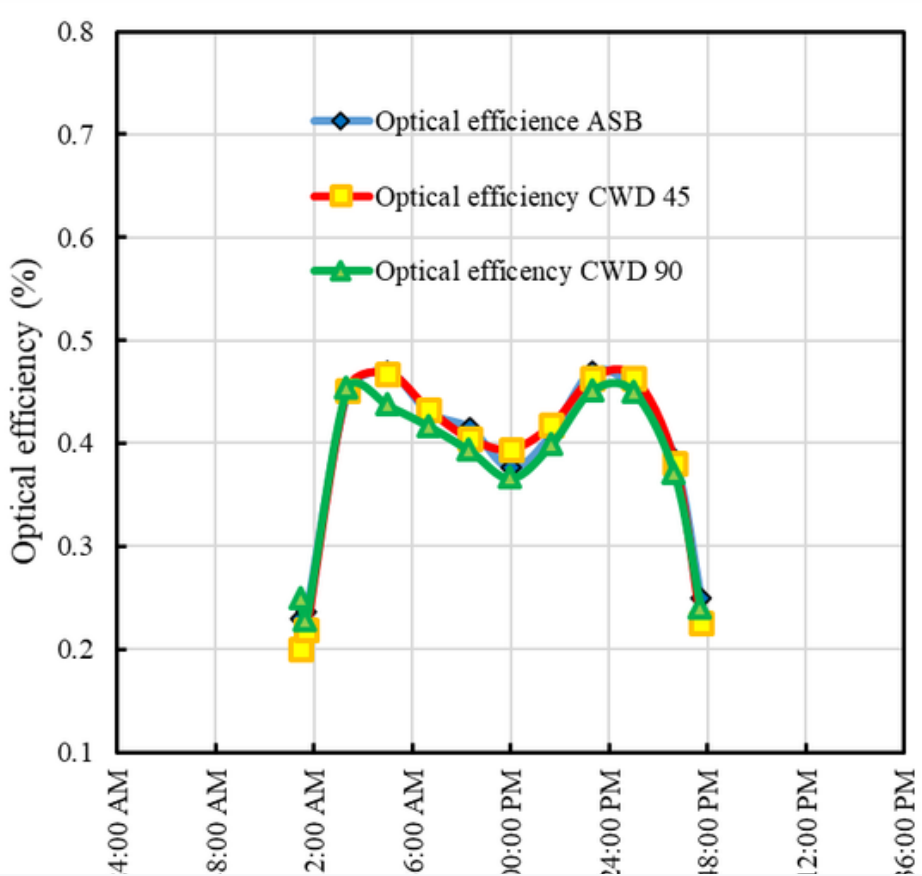
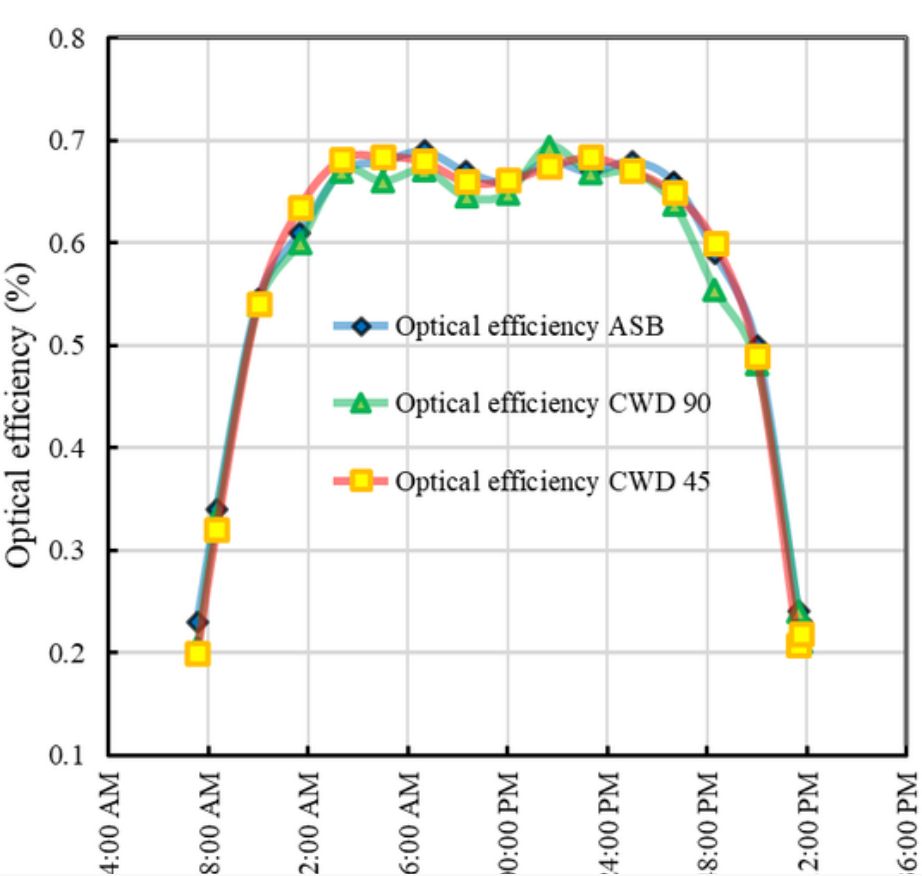
Standard deviation of wall flux: how uniform the loading is

Interception factor: how stable the optical capture remains



A receiver can be optically efficient but thermally unfavourable if flux is too concentrated.

Optical efficiency across locations and seasons



CWD designs maintain competitive daily optical efficiency under different solar-angle conditions.

Flux redistribution: ASB vs CWD absorbers

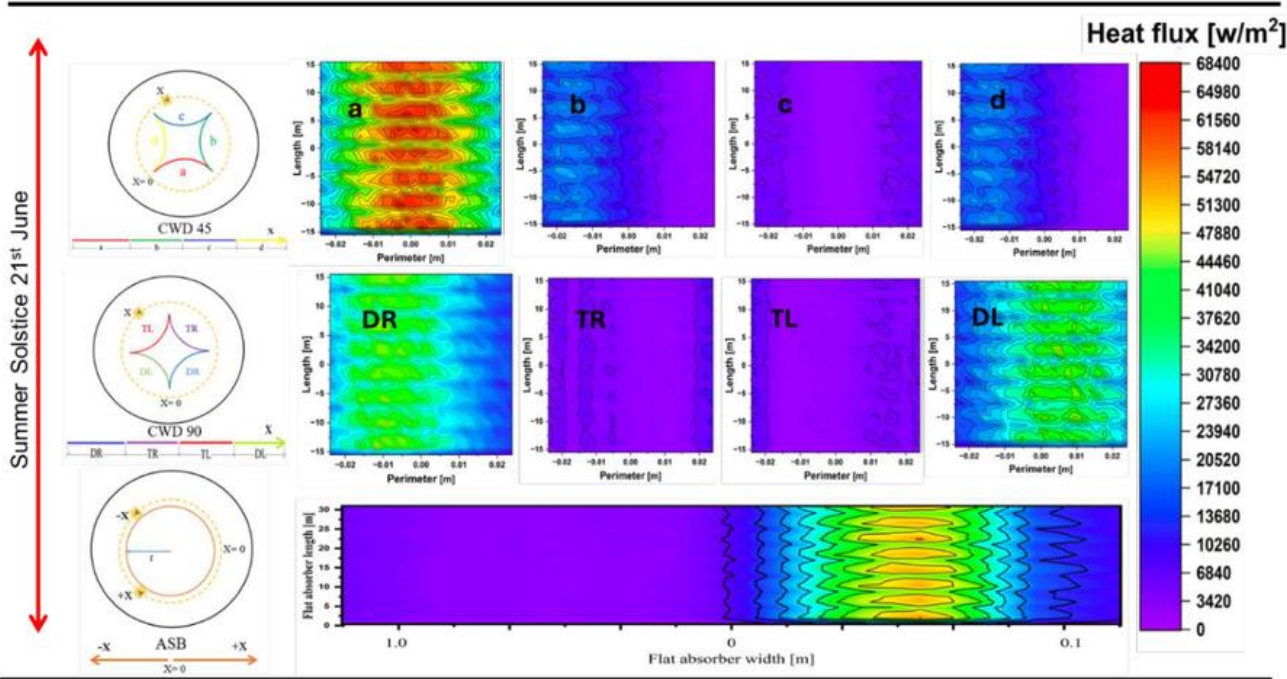


Figure 56: Flux distribution for the three designs (CWD 45°, CWD 90°, and ASB) at 12:00 PM in Nicosia during the summer solstice.

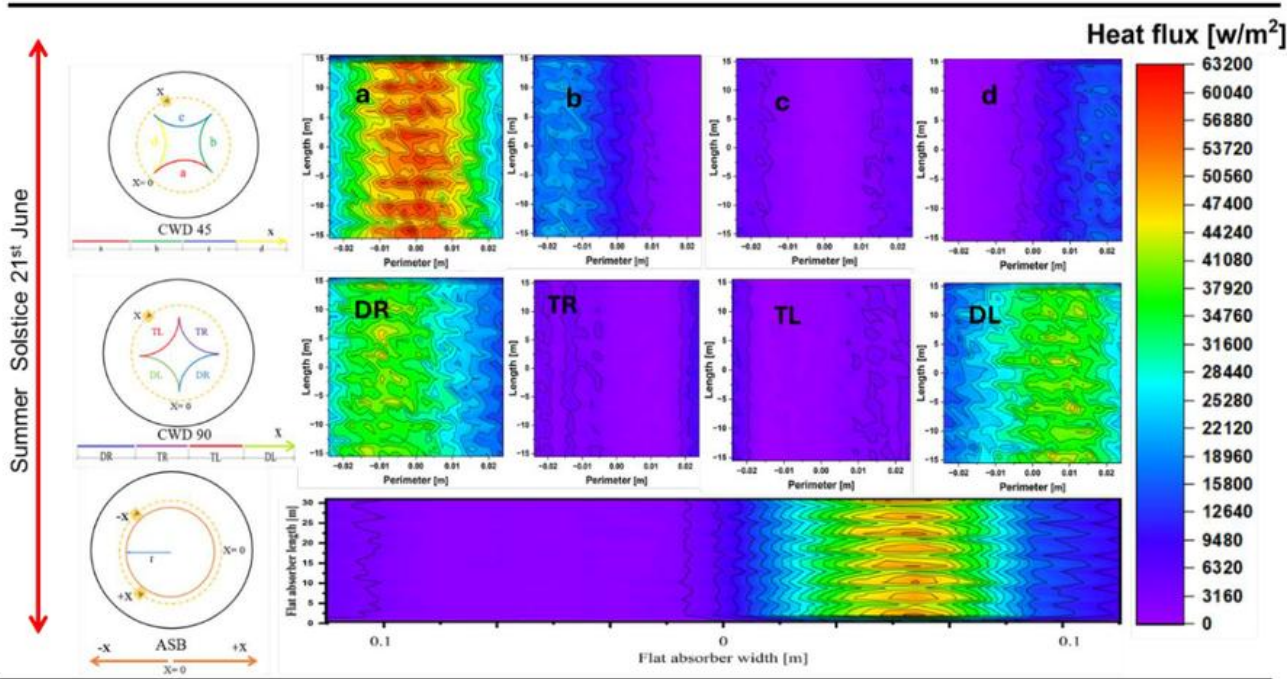


Figure 57: Flux distribution for the three designs (CWD 45°, CWD 90°, and ASB) at 12:00 PM in Khartoum during the summer solstice.

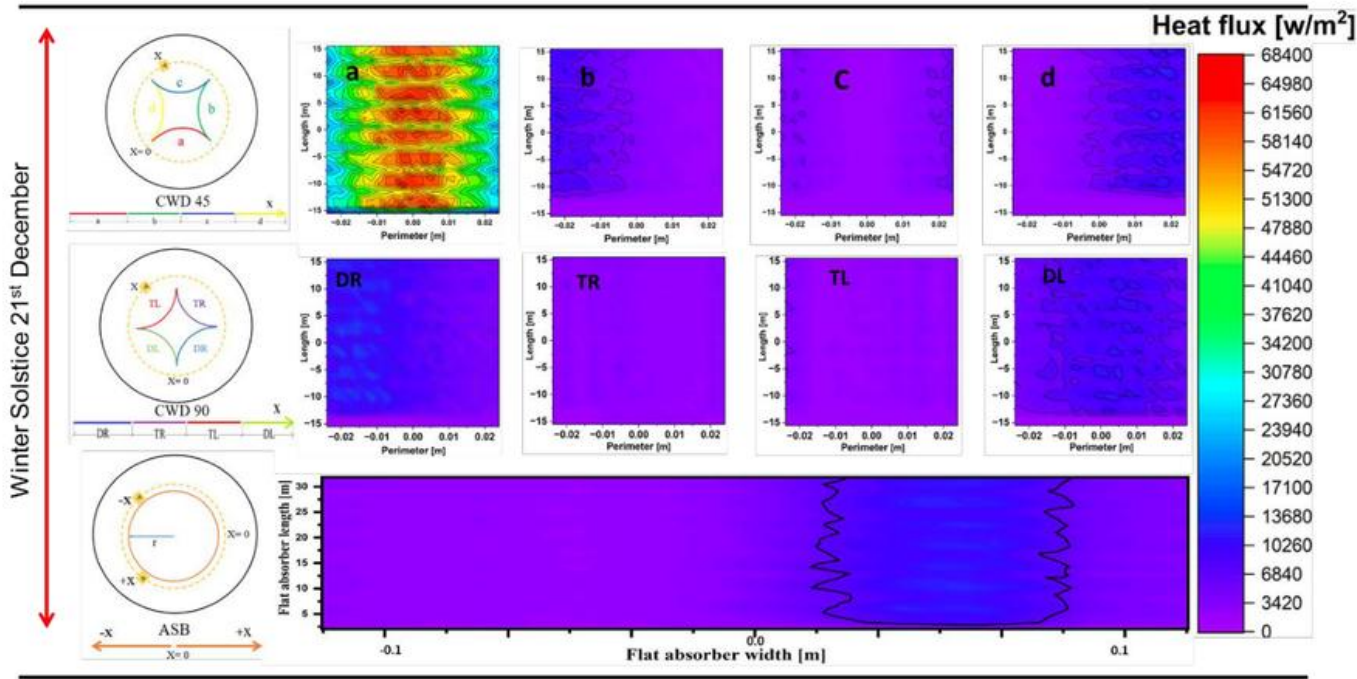


Figure 59: flux distribution for three designs (CWD 45°, CWD 90° and ASB) at 8 am for Nicosia city during the winter solstices.

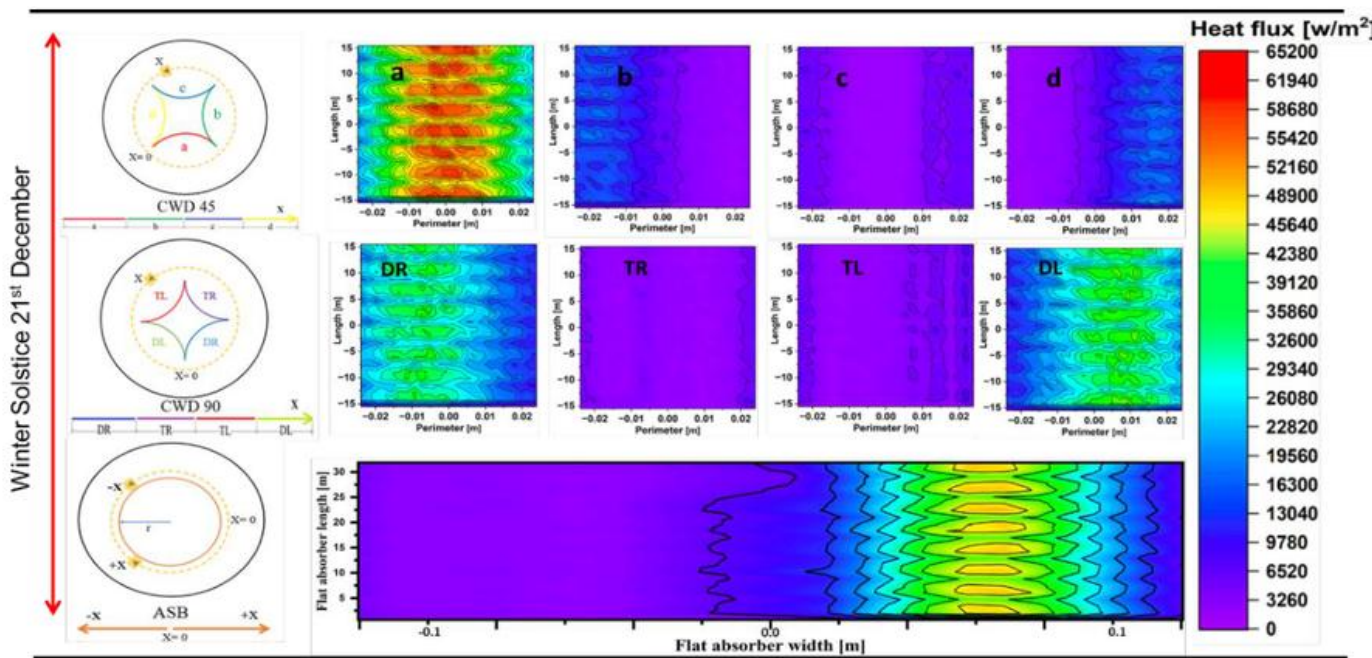


Fig 60: flux distribution for three designs (CWD 45°, CWD 90° and ASB) for Khartoum city during the 8 am winter solstice.

CWD-90 redistributes rays over the absorber walls and reduces local concentration.

Location	Season	Time	Design	Mean Absorbed Flux (kW/m ²)	Standard Deviation (Sq") (kW/m ²)	Improvement in Uniformity (ASB vs. CWD 90°)
Khartoum (15.56°N)	Summer	8 am	ASB	15.1	15.7	~15.3%
			CWD 45°	15.0	17.4	
			CWD 90°	14.8	13.3	
	Summer	12 pm	ASB	16.7	16.5	~10.3%
			CWD 45°	16.3	16.8	
			CWD 90°	16.2	14.8	
	Winter	8 am	ASB	15.8	15.4	~14.3%
			CWD 45°	16.1	17.3	
			CWD 90°	15.4	13.2	
	Winter	12 pm	ASB	16.5	16.4	~23.2%
			CWD 45°	16.8	18.2	
			CWD 90°	16.2	12.6	
Nicosia (35.14°N)	Summer	8 am	ASB	14.6	16.0	~13.8%
			CWD 45°	14.8	18.0	
			CWD 90°	14.3	13.8	
	Summer	12 pm	ASB	16.0	16.5	~10.9%
			CWD 45°	16.1	18.2	
			CWD 90°	15.7	14.7	
	Winter	8 am	ASB	6.8	4.0	~2.5%
			CWD 45°	7.1	19.1	
			CWD 90°	6.6	3.9	
	Winter	12 pm	ASB	9.1	5.6	~5.4%
			CWD 45°	9.6	19.2	
			CWD 90°	8.9	5.3	
Miskolc (48.3°N)	Summer	8 am	ASB	13.5	15.9	~13.8%
			CWD 45°	13.6	18.6	
			CWD 90°	13.3	13.7	
	Summer	12 pm	ASB	15.1	14.3	~9.8%
			CWD 45°	14.8	16.0	
			CWD 90°	14.5	12.9	
			ASB	6.1	3.3	

Main optical finding: CWD-90 improves flux uniformity

20–23%

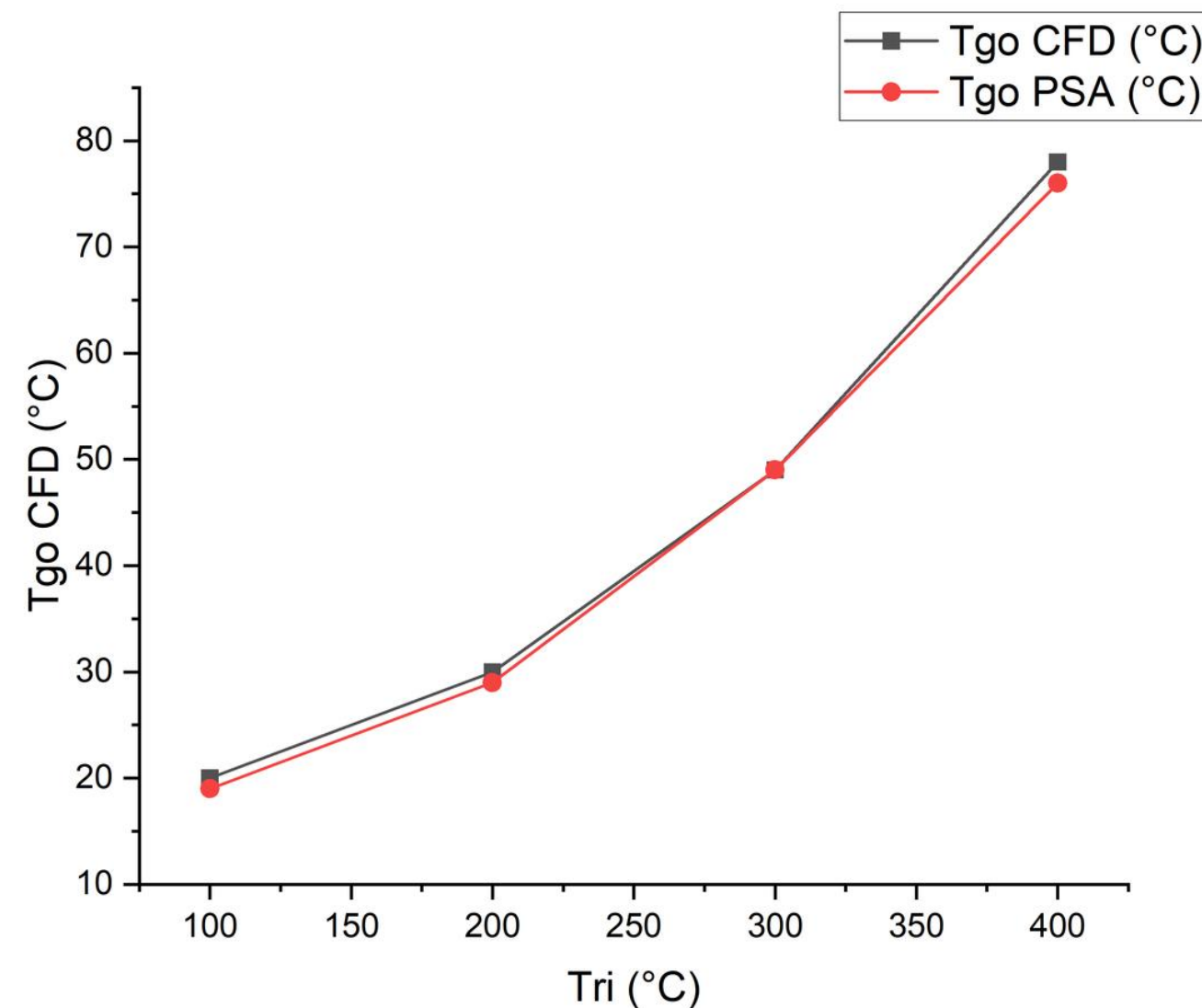
reduction in circumferential flux non-uniformity

CWD-90 gives the best balance

CWD-45 can improve efficienc but may worsen uniformity

Flux uniformity becomes a receiver-design criterion alongside optical efficiency.

Thermal assessment: ASB vs CWD-90



Use validated PTR70 thermal framework
Import ASB and CWD-90 flux maps from optical analysis
Compare temperature distribution, gradients, heat loss, and thermal behaviour

This links optical flux improvement to thermal consequences.

CHAPTER 5

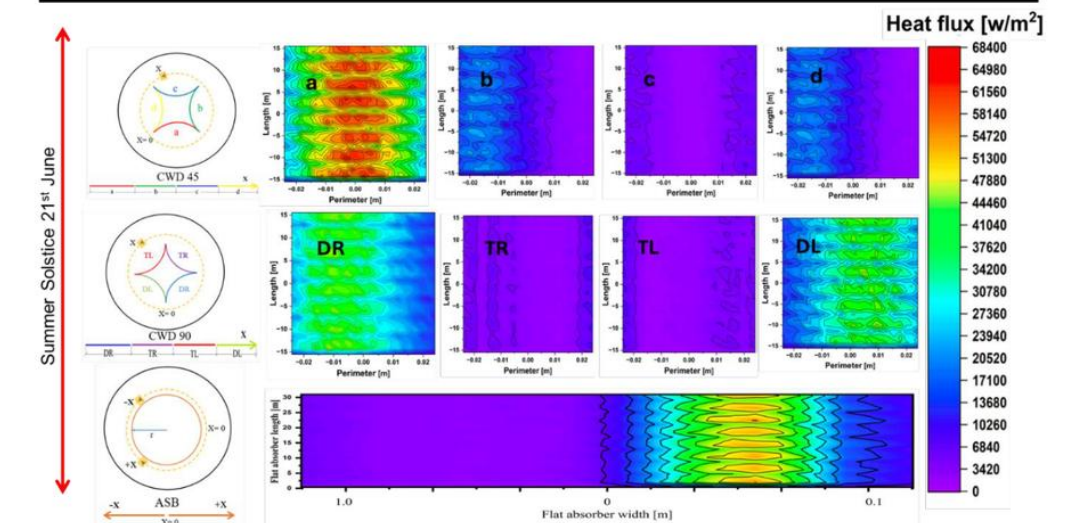


Figure 56: Flux distribution for the three designs (CWD 45°, CWD 90°, and ASB) at 12:00 PM in Nicosia during the summer solstice.

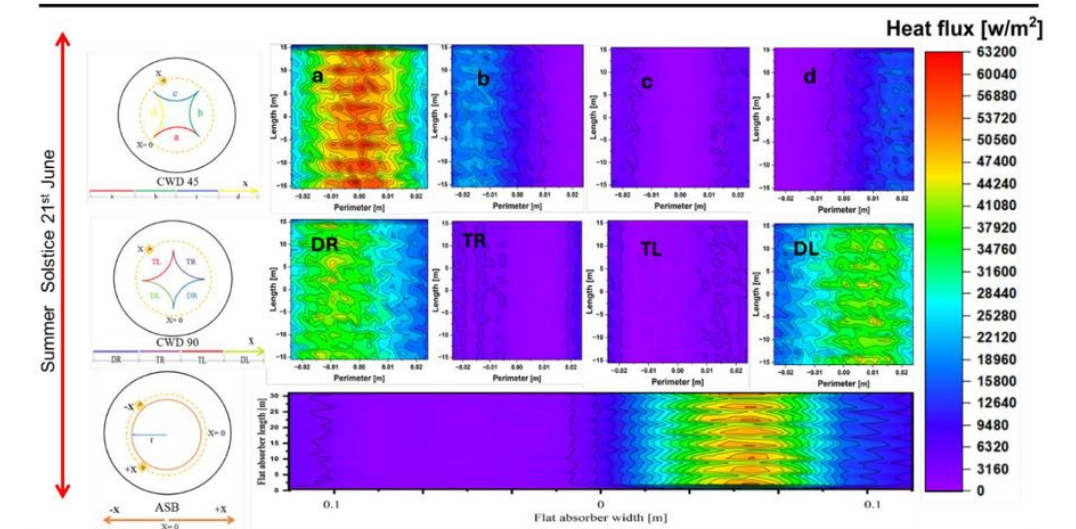


Figure 57: Flux distribution for the three designs (CWD 45°, CWD 90°, and ASB) at 12:00 PM in Khartoum during the summer solstice.



Integrated discussion: what changed from stage to stage?

5%

dual-tube thermal
improvement

5.1% / 3.0%

PTR70 validation deviations

20–23%

CWD-90 flux-uniformity
improvement

Non-vacuum path: low-cost receiver improvement

Evacuated path: validated PTR70 framework and flux redistribution

Design logic: assess → validate → improve → compare





Theses – new scientific results

T1 – Validated optical-thermal methodology for single/dual non-vacuum receivers

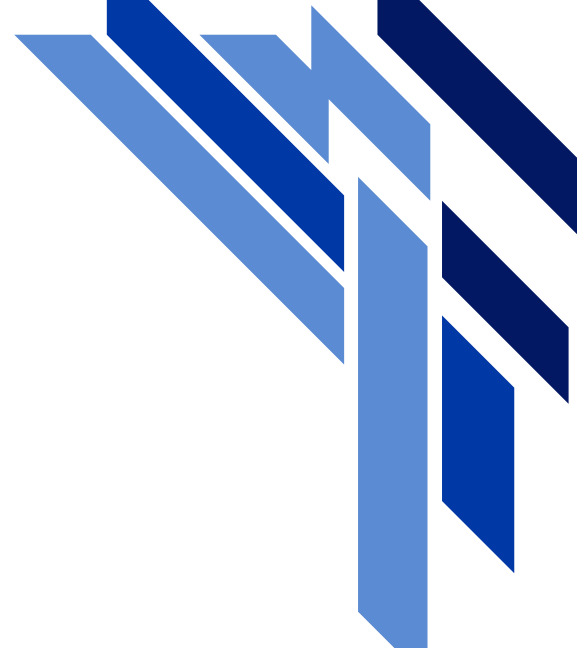
T2 – Benchmark-validated thermal model of the commercial PTR70 receiver

T3 – Concave-wall absorber geometries for passive flux redistribution

T4 – Thermal assessment pathway for ASB vs CWD-90 evacuated receivers

The contribution is not one component: it is an integrated receiver-development framework.





Final message

Linear Fresnel receiver performance can be improved by matching the right method to the right design problem: optical redistribution, thermal loss reduction, experimental validation, and benchmark-validated CFD are complementary tools.

THANK YOU

Questions?

