Thermal Receivers

A Review of Papers Presented at SolarPACES 2015

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Sandia National Laboratories

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

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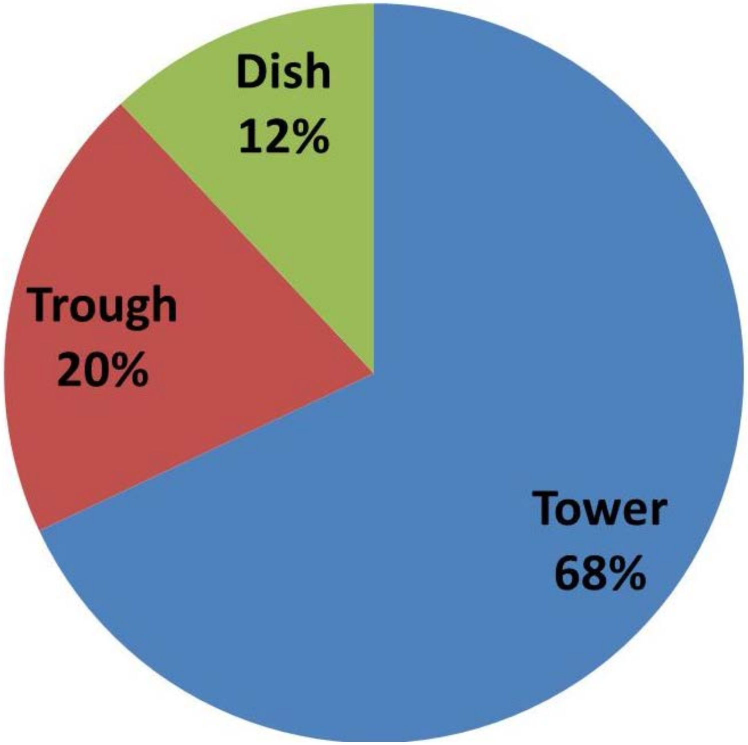
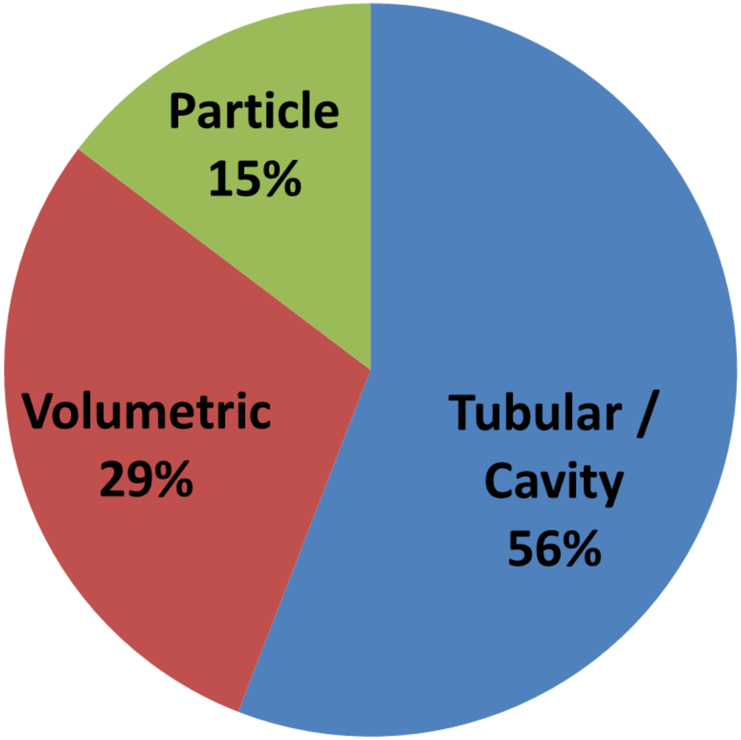
NNSA National Nuclear Security Administration

Paper Statistics

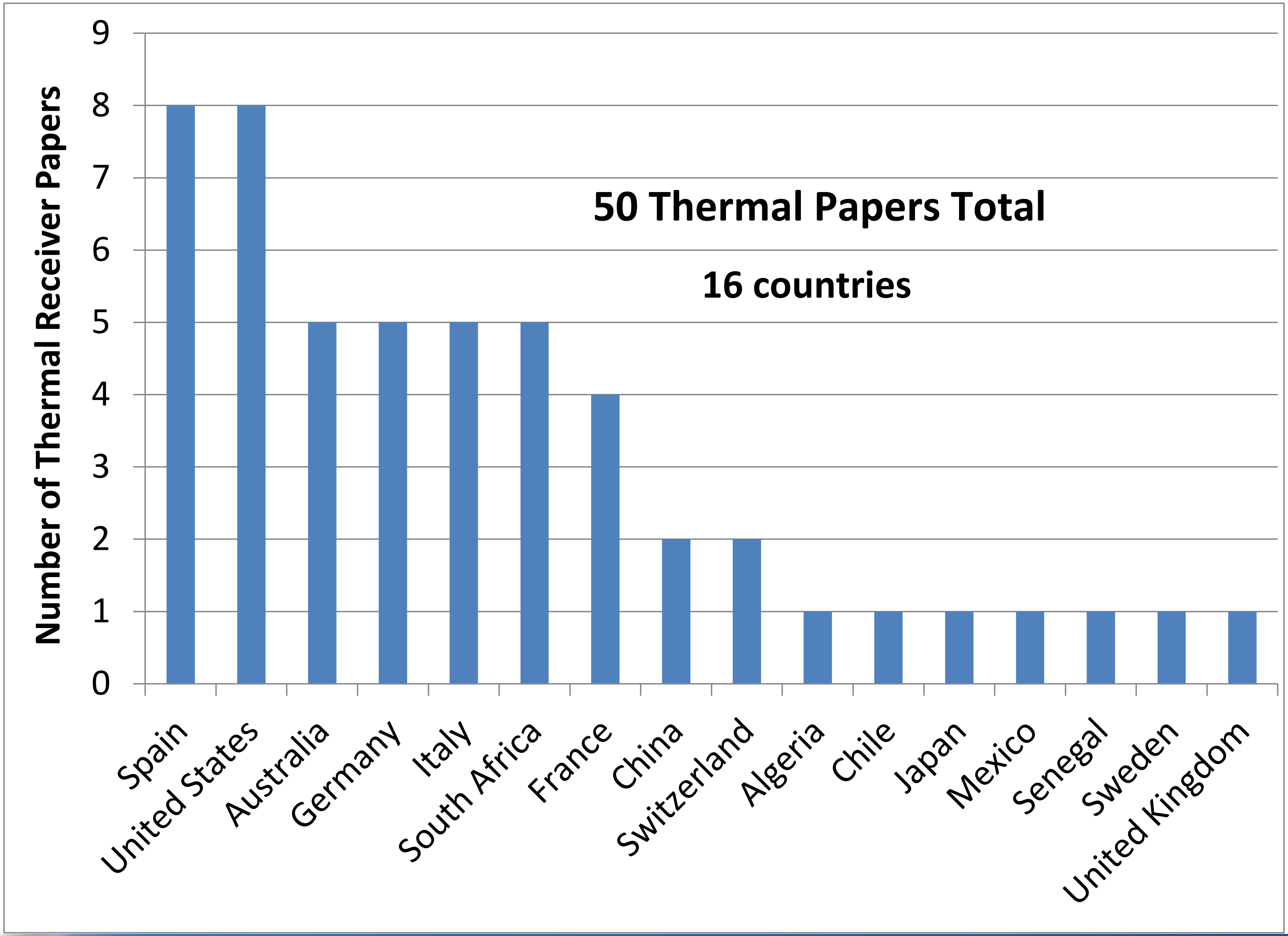
50 Thermal Receiver Papers



Tower Receivers (34 papers)



Papers by Country



Receiver Categories

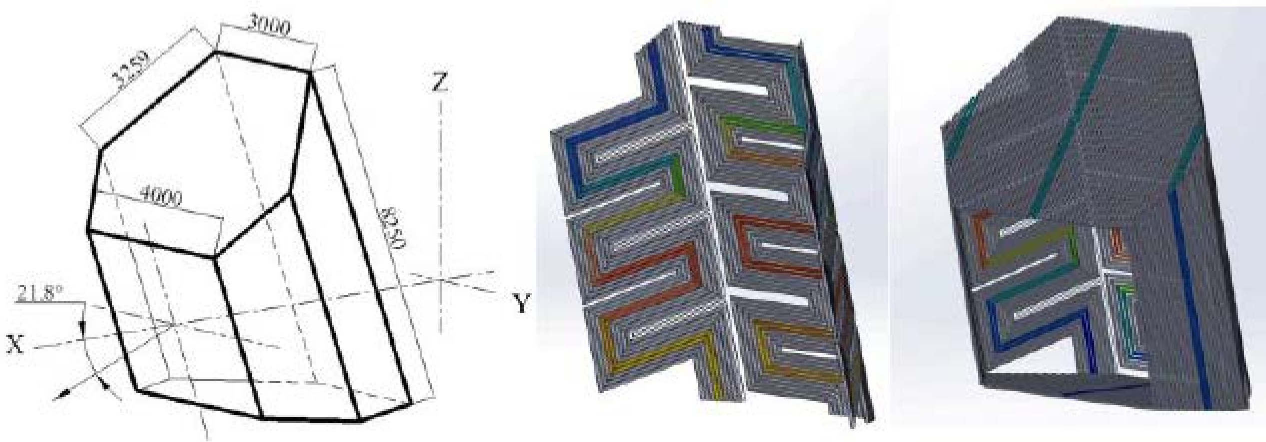
- Tower Receivers
- Parabolic Trough / Line-Focus Receivers
- Dish Receivers

Advances in Tower Receivers

- Tubular / Cavity Receivers
- Volumetric Air Receivers
- Particle Receivers

Numerical Investigation on the Effect of Tube Layout on the Heat Loss of Solar Cavity Receiver

(Fang et al., Jiaotong University)



(a) Cavity geometry (b) Tube layout-1 (c) Tube layout-2

FIGURE 1. Geometry of cavity and tube layouts

Simulations showed that lining passive surfaces of a tubular cavity receiver with preheating/boiler tubes reduced wall temperatures by 200 – 300 C and increased efficiency by 3 – 5%.

Optimal Spacing within a Tubed, Volumetric, Cavity Receiver Suitable for Modular Molten Salt Solar Towers

(Turner, Cranfield University)

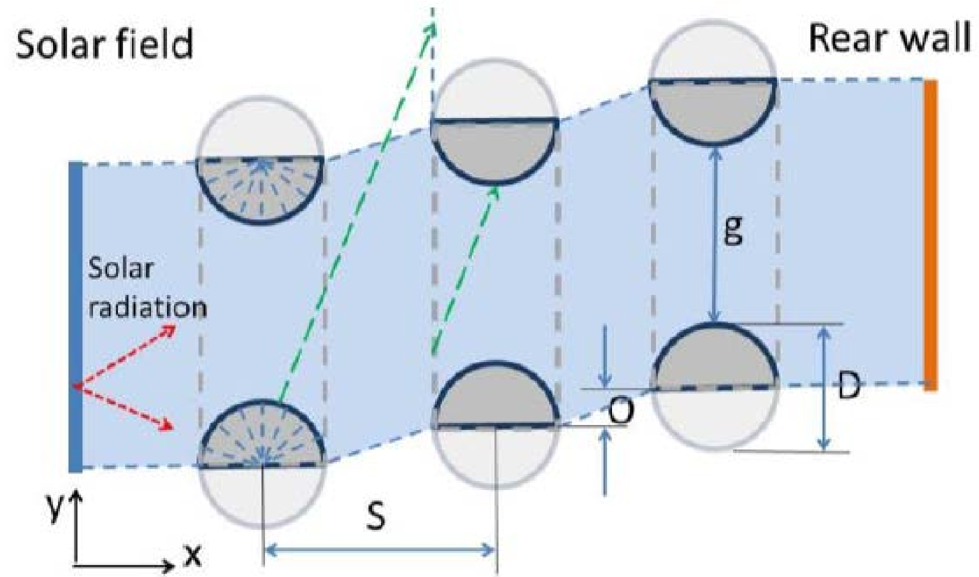
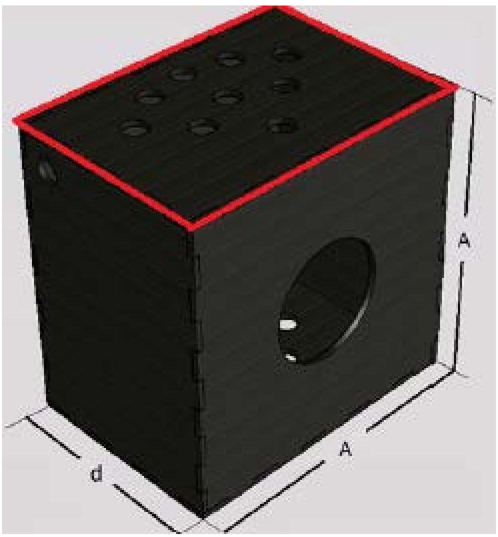


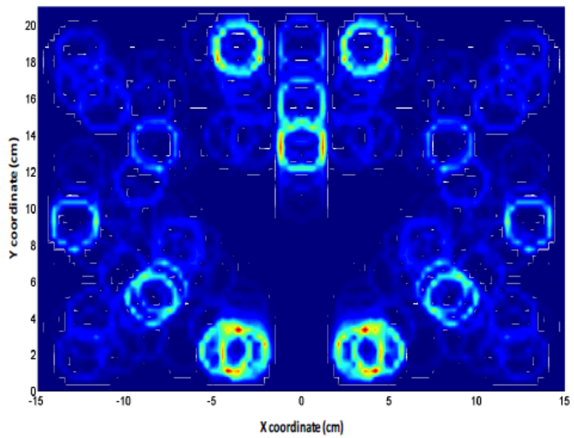
FIGURE 1: Two-dimensional receiver model showing 3-tube-layers

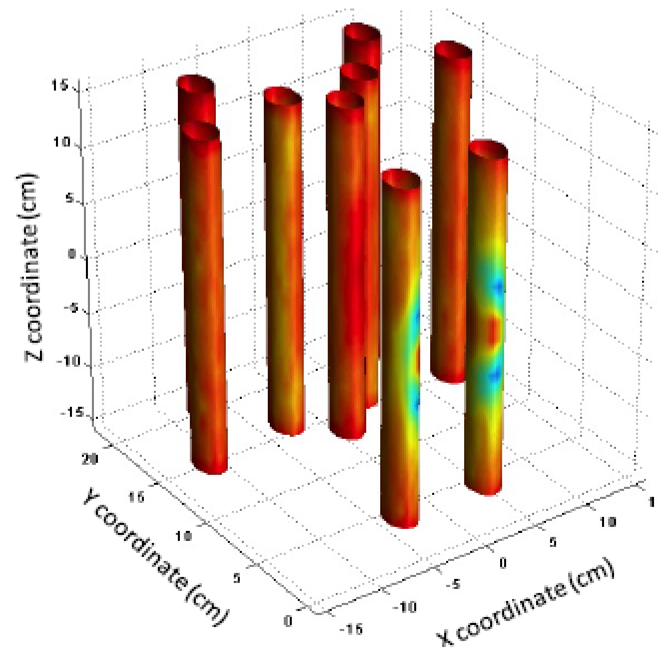
Simulations of a volumetric array of molten-salt tubes shows reduced radiation losses and increased efficiency.

Geometric Optimization of a Solar Cubic-Cavity Multi-Tubular Reactor

(Valades-Pelayo et al., Universidad Nacional Autónoma de México)



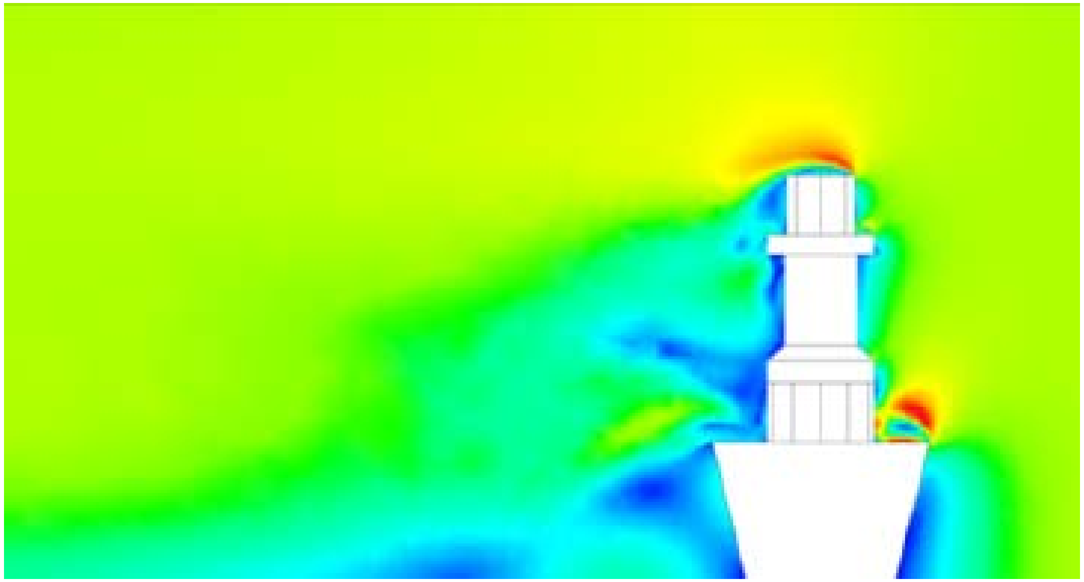




Tube arrangement in cavity receiver optimized to maximize tube temperature and minimize gradients for high-temperature thermochemical reactions.

Effects of vertically ribbed surface roughness on the forced convective heat losses in central receiver system

(Uhlig et al., DLR)



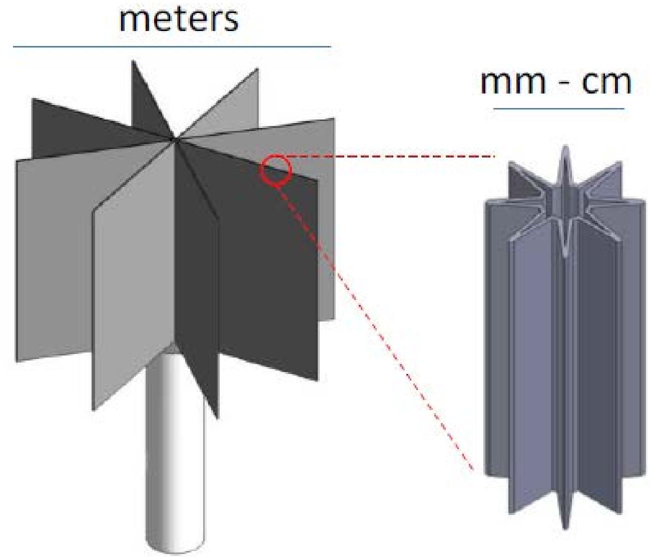
Modeled heat loss and thermal efficiency of Solar Two molten salt receiver with inclusion of tube features and circumferentially varying heat loss.

Fractal-Like Receiver Geometries and Features for Increased Light Trapping and Thermal Efficiency

(Ho et al., Sandia National Laboratories)

~10 m

Conventional cylindrical solar receiver



New fractal-like designs with increased light-trapping features at multiple length scales

Light-trapping geometries and features at multiple length scales were modeled and tested and shown to increase effective solar absorptance and thermal efficiency.

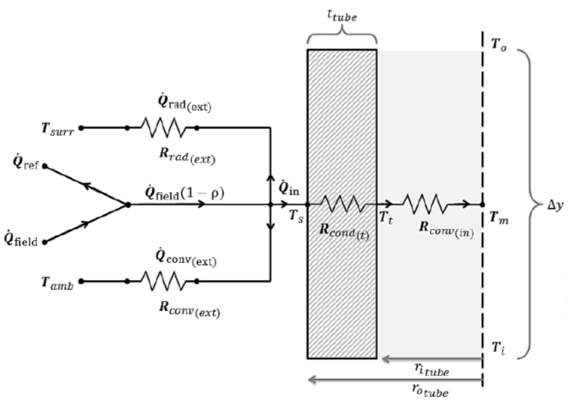
Reducing the Convective Losses of Cavity Receivers

(Flesch et al., DLR)

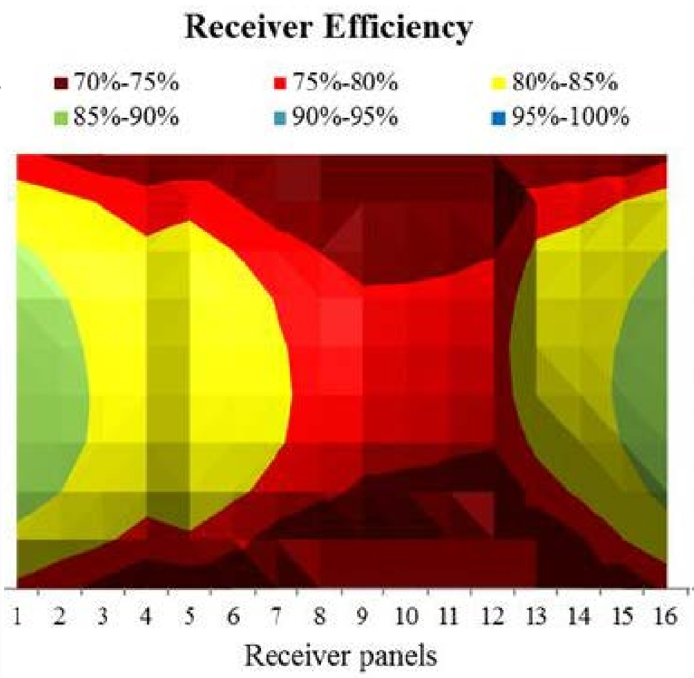
Modeling and testing of air curtain and partial window showed reduction in convective heat losses by up to 50%. Authors proposed using natural convection from heat shields to create natural air curtain from wind.

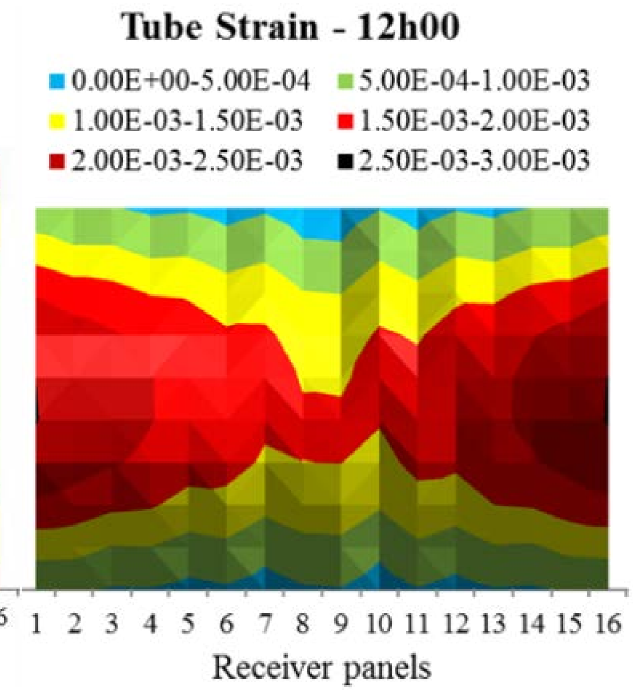
Thermal Resistance Model for CSP Central Receivers

(de Meyer et al., Stellenbosch U.)

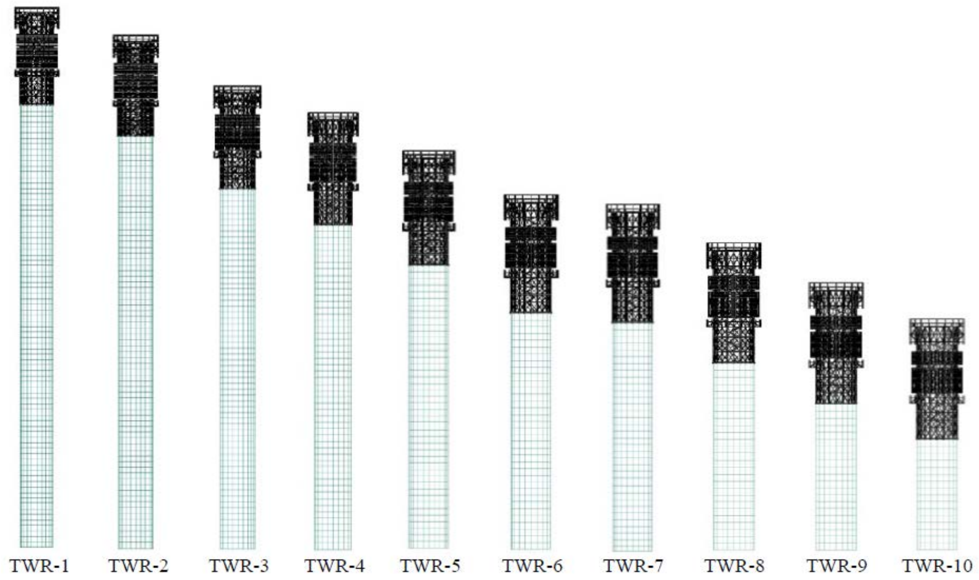


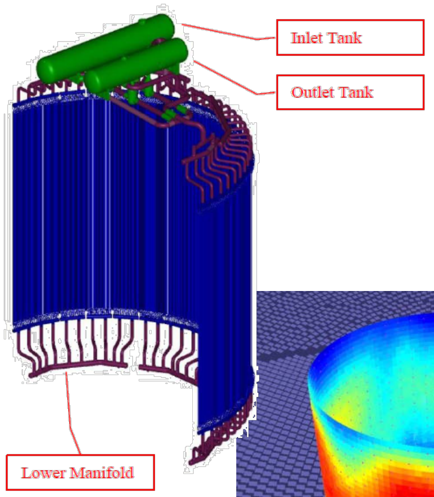
Thermographic maps. Use flux map and heat transfer coefficients as inputs to estimate thermal/structural performance

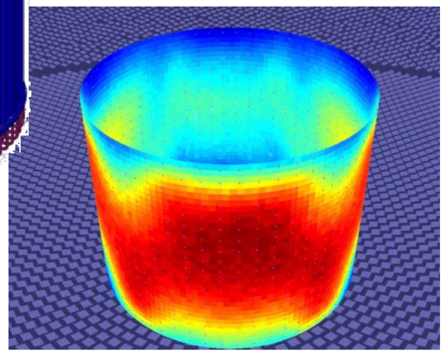




- Alstom Molten Salt Central Receiver Modeling & Design
  - Transient Simulation of Molten Salt Central Receiver (Doupis et al.)
  - Thermo-Mechanical and Optical Optimization of the Molten Salt Receiver for a Given Heliostat Field (Augsburger et al.)
  - Analytical Study of Seismic Effects of a Solar Receiver Mounted on Concrete Towers with Different Fundamental Periods (Deng)



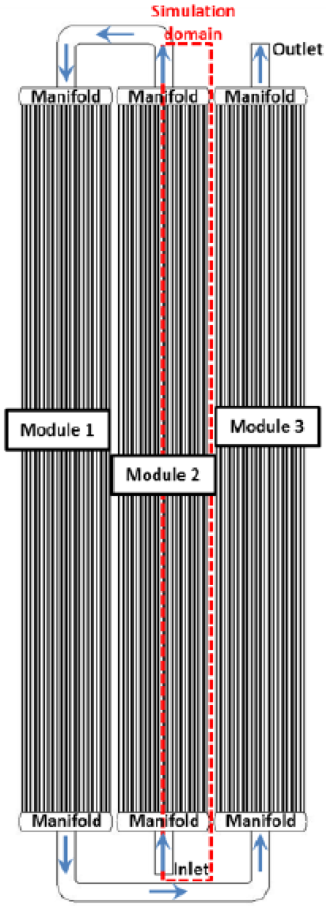




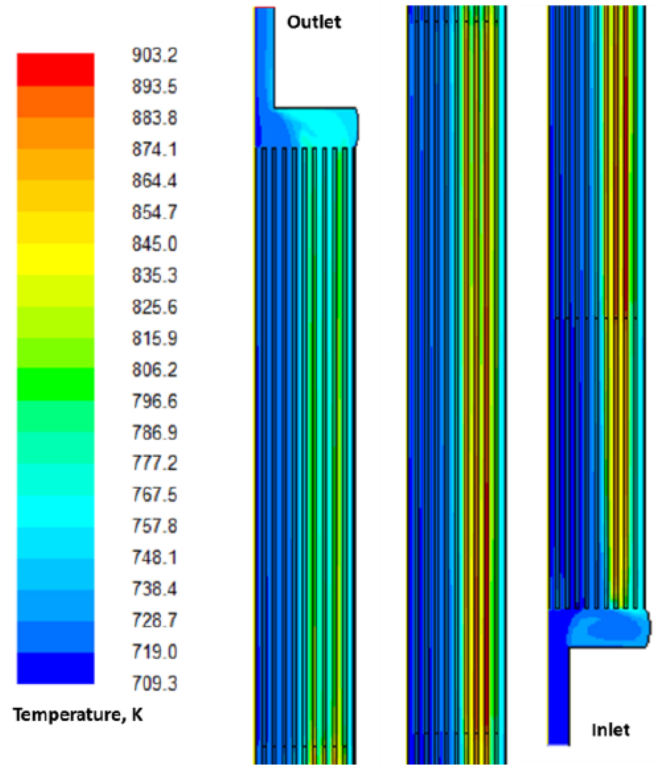
Alstom investigated start-up, shutdown, and transient operation strategies for molten salt central receiver. Developed optimization procedure for receiver and heliostat field. Performed seismic evaluation with and without dead loads and compared to ASCE code.

CFD analysis of supercritical CO_2 used as HTF in a solar tower receiver

(Roldan and Fernandez-Reche, CIEMAT)



CFD simulations showed greater heat absorption using sCO_2 vs. molten salt for a tubular receiver panel, and sCO_2 is a feasible alternative to molten salt.



Advances in Tower Receivers

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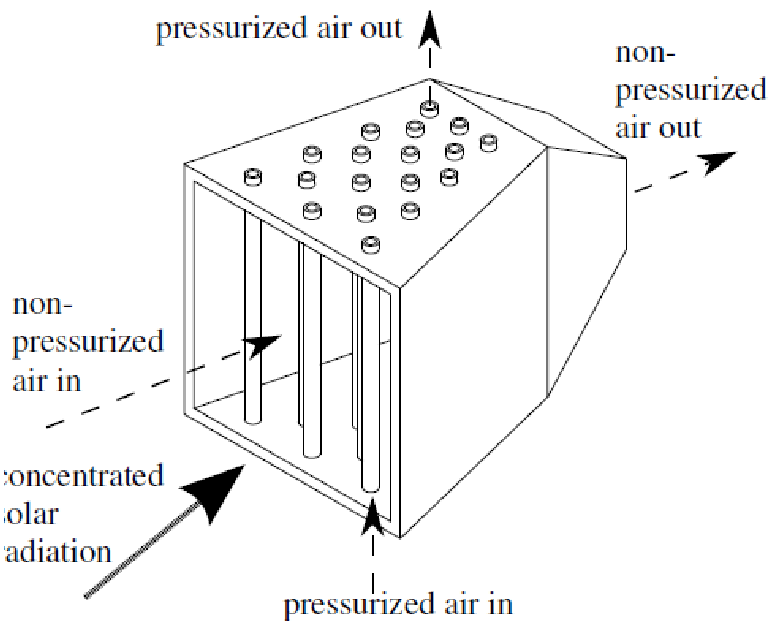
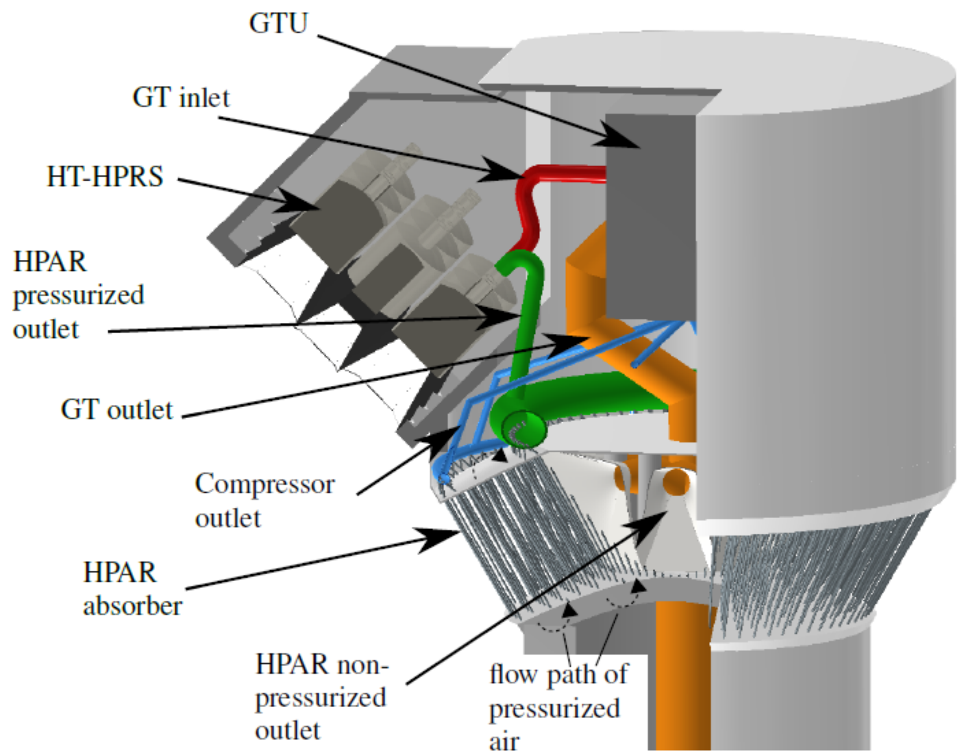
- Volumetric Air Receivers
- Particle Receivers

The Hybrid Pressurized Air Receiver (HPAR) in the SUNDISC Cycle

(Heller et al., Stellenbosch University)





Pressurized air is heated in staggered array of tubes while unpressurized air is heated around tubes for air Brayton cycle. Simulations show transfer to non-pressurized air needs improvement.

Performance Outlook of the SCRAP Receiver

(Lubkoll et al., Stellenbosch University)

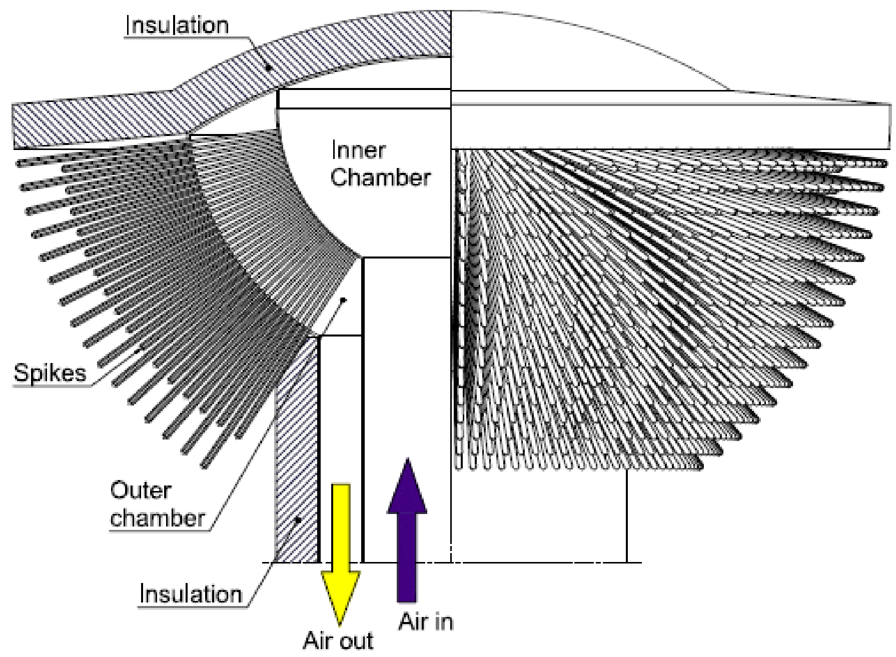
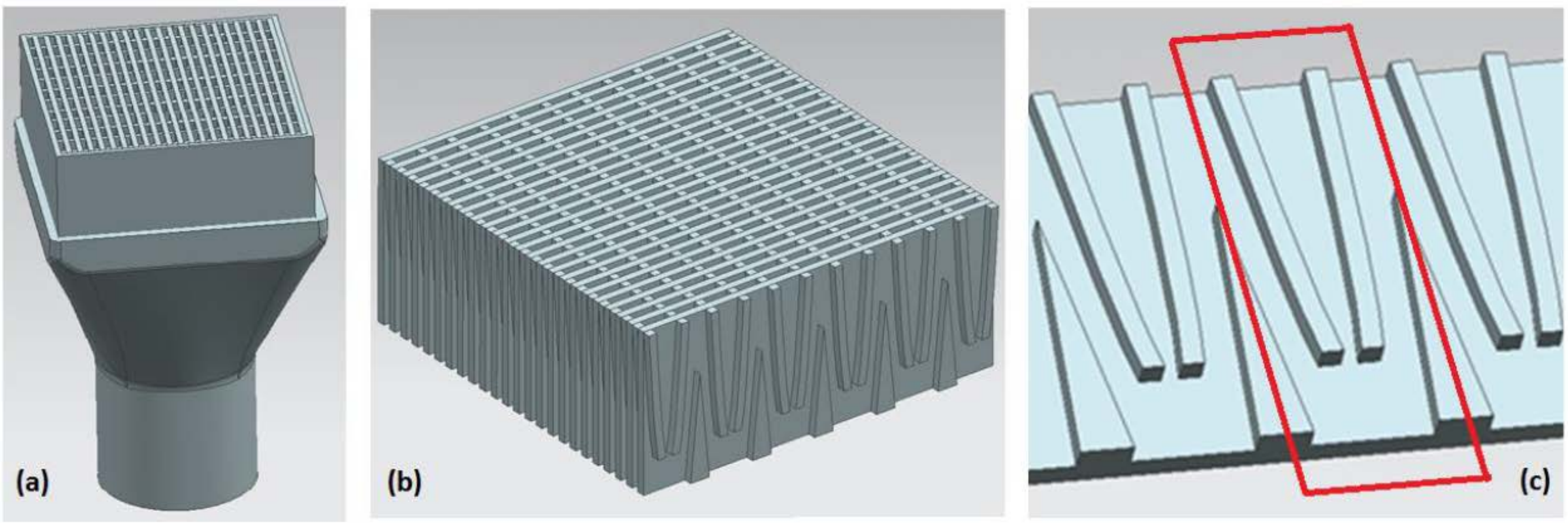


FIGURE 1: A manifestation of the SCRAP receiver (left half in section) [3]

Pressurized Spiky Central Receiver Air Pre-heater. CFD simulations of air flow through each spike with 1 MW/m^2 yielded 80% efficiency and 800 C outlet air temperature. <u>Only 3% radiative heat losses</u>.

Numerical Evaluation of an Innovative Cup Layout for Open Volumetric Solar Air Receivers

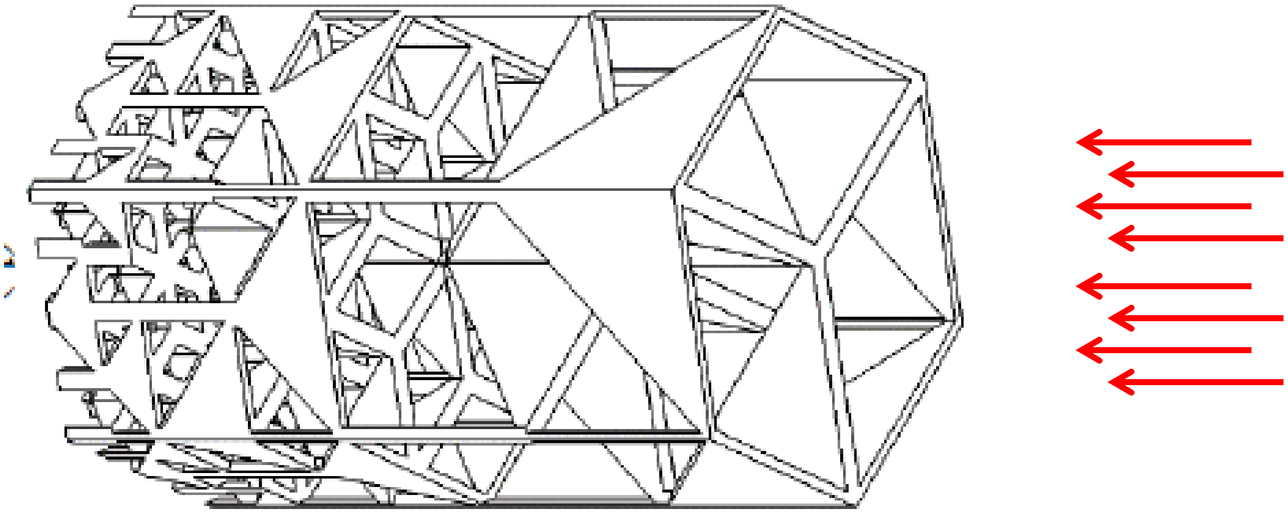
(Savoldi et al., Politecnico di Torino)



A new channel design implementing CPC shapes to allow more light penetration resulted in simulated thermal efficiency of 69% compared to 85% for conventional honeycomb. Room for optimization.

Numerical Analysis of Radiation Propagation in Innovative Volumetric Receivers Based on Selective Laser Melting Techniques

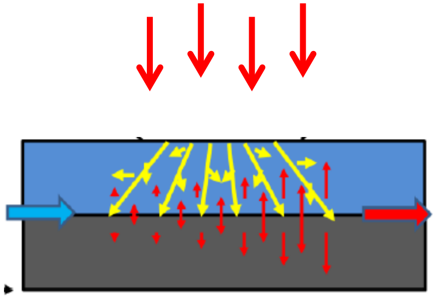
(Alberti et al., Fondazione Bruno Kessler, IMDEA)



Multi-porosity volumetric absorber has larger openings near the aperture to allow more light penetration and lower temperatures at the aperture.

Preliminary Performance Analysis of a Transverse Flow Spectrally Selective Two-slab Packed Bed Volumetric Receiver

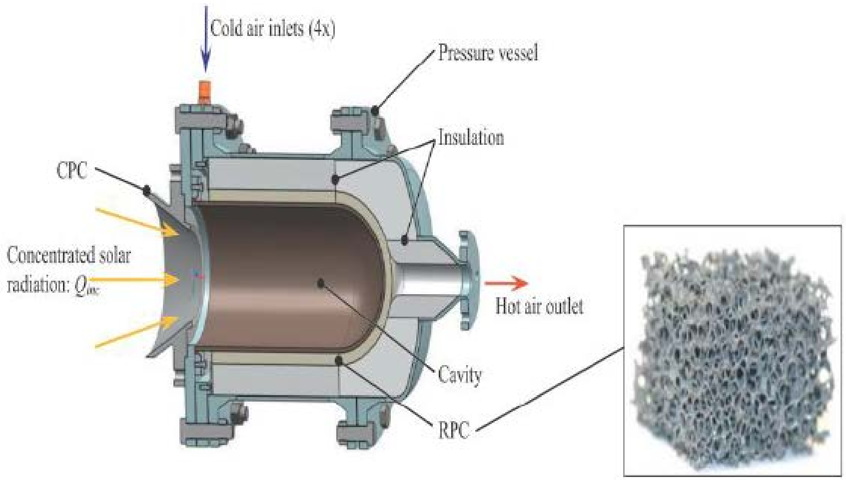
(Roos and Harms, CSIR and U. of Stellenbosch)

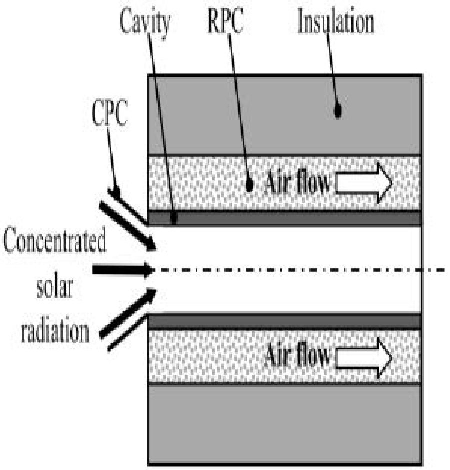


Transparent (borosilicate) beads near aperture allow light to penetrate to opaque (SiC) beads beneath.

Study and Modeling of a Pressurized Air Receiver to Power a Micro Gas Turbine

(Ndiogou et al., Ecole Supérieure Polytechnique de Dakar)

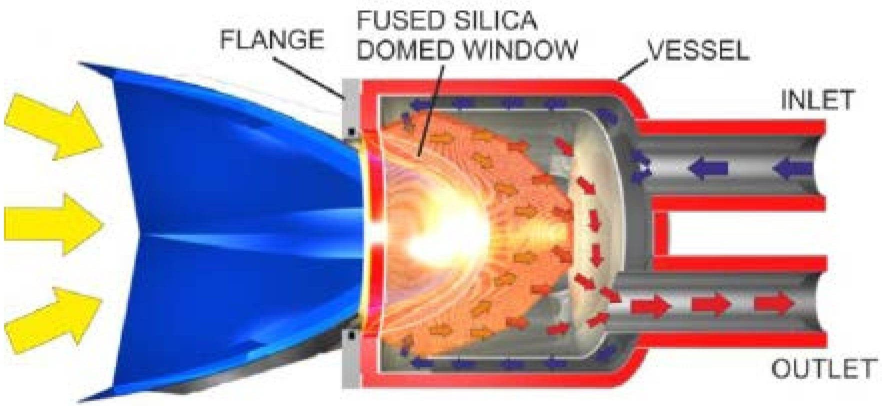


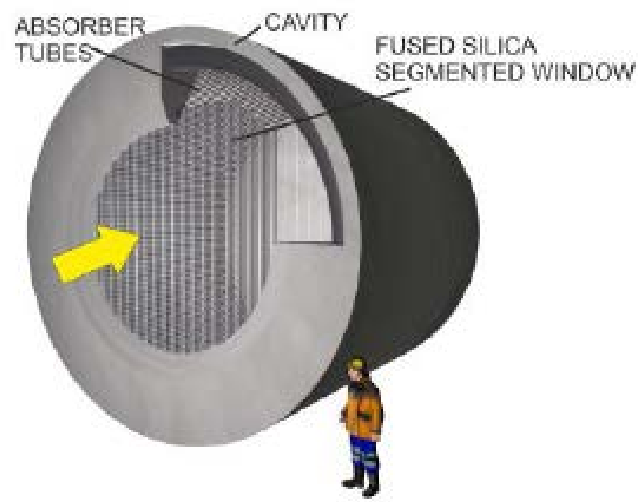


Simulated performance of mass flow and porosity on thermal efficiency of pressurized air receiver.

Fused Silica Windows For Solar Receiver Applications

(Hertel et al., DLR)





FEA and testing of pressurized domed quartz windows and segmented windows showed feasibility of operation at 800 C and design strength of 6 MPa. Cleaning is required to prevent crystallization.

Advances in Tower Receivers

- Tubular / Cavity Receivers
- Volumetric Air Receivers
- Particle Receivers

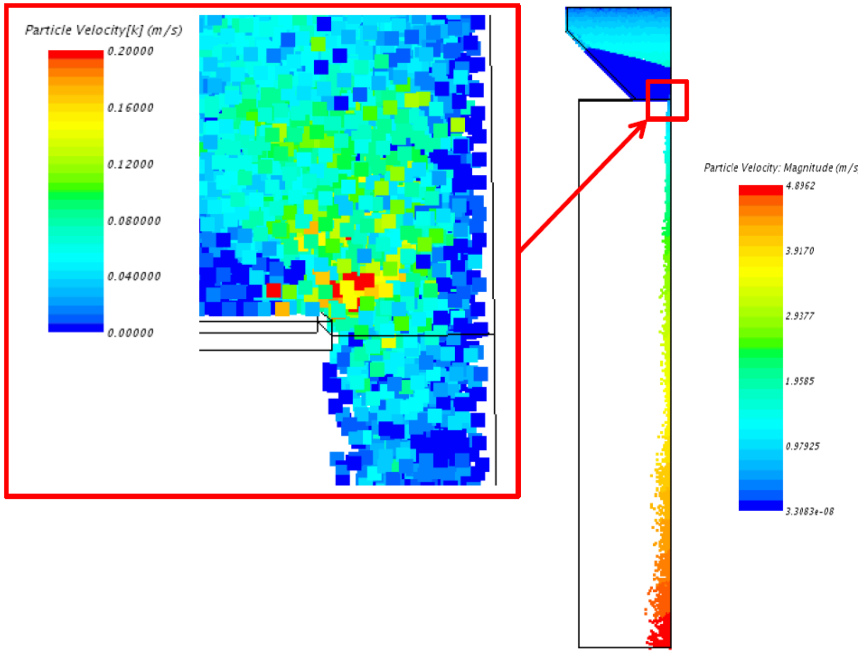
On-sun first operation of a 100 kWth pilot solar receiver using dense particle suspension as heat transfer fluid

(Perez Lopez et al., PROMES-CNRS)

Tests of Dense Particle Suspension (fluidization) in tubes yielded average outlet temperature of 590 C and thermal efficiencies of 50 – 90%

Preliminary Discrete Element modeling of a falling particle curtain for CSP central tower receivers

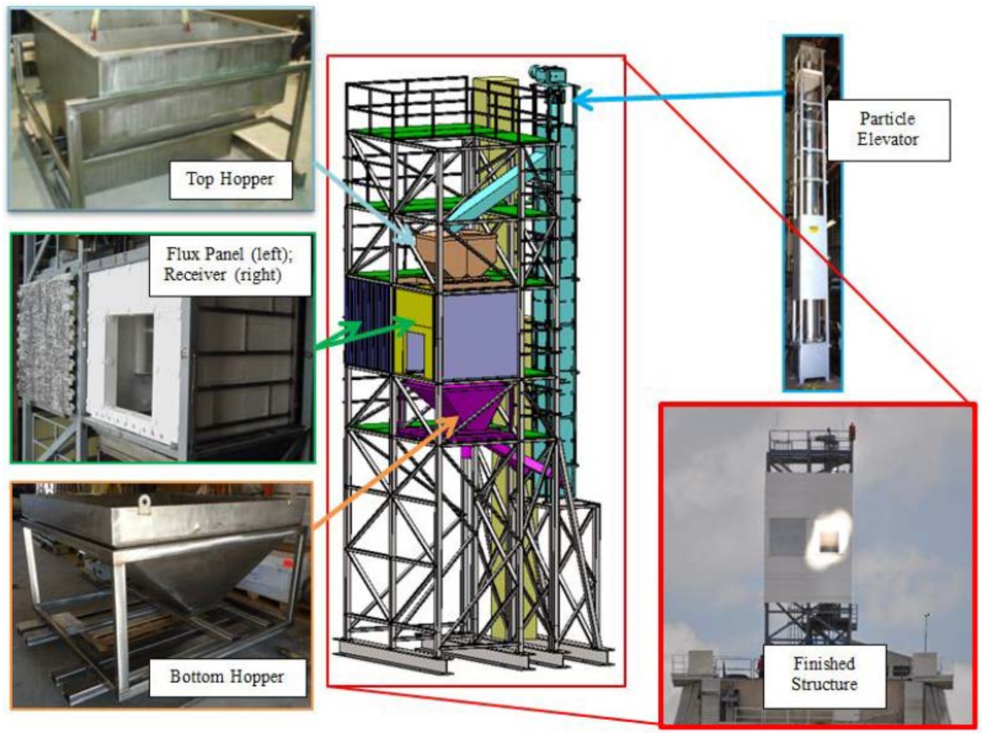
(Zanino et al., Politecnico di Torino)



Discrete Element Modeling of falling particle receivers show additional effects of particle-particle interaction on curtain thickness.

Design Requirements, Challenges, and Solutions for High-Temperature Falling Particle Receivers

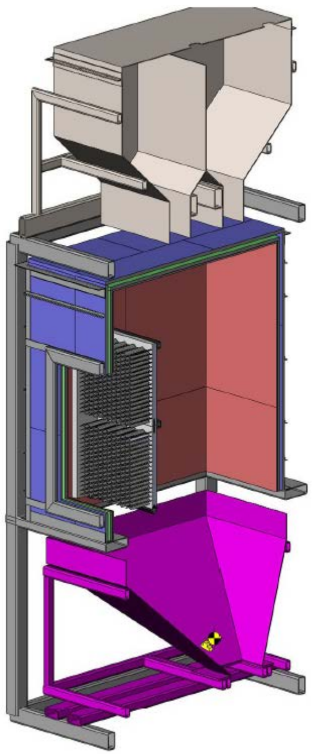
(Christian and Ho, Sandia National Laboratories)

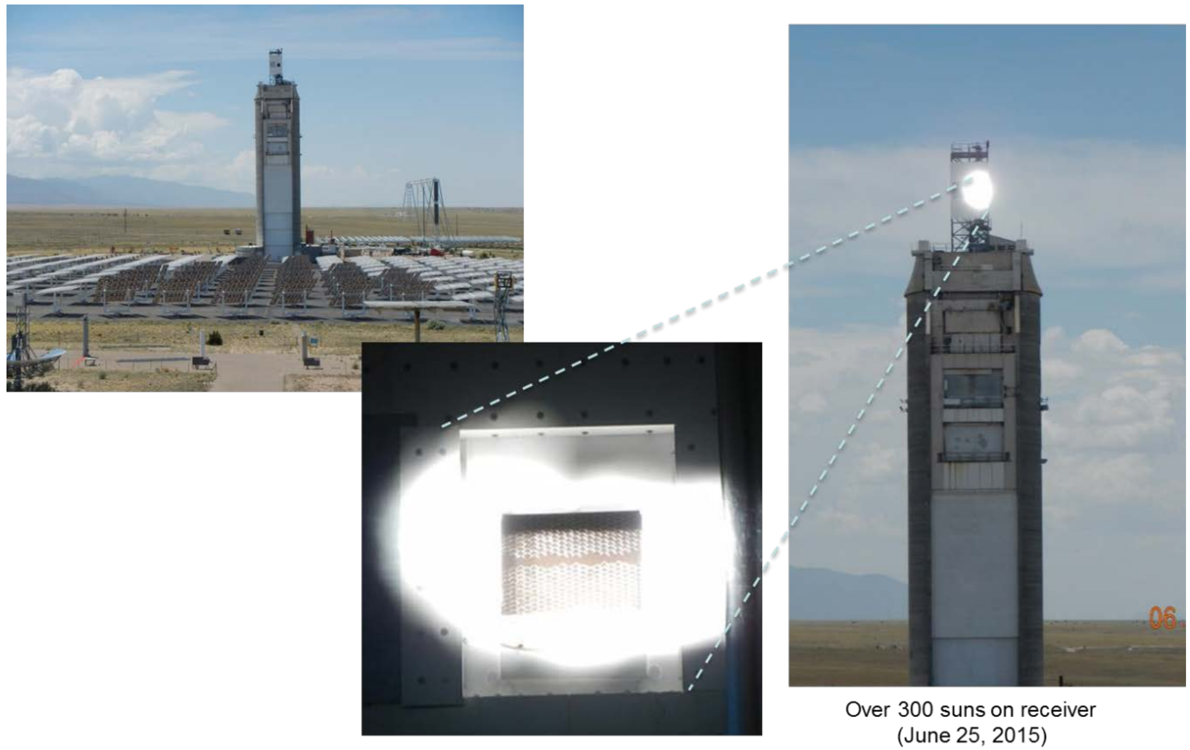


Design requirements and lessons learned from design and construction of a prototype 1 MWth on-sun falling particle receiver system were presented.

On-Sun Testing of an Advanced 1 MW_{th} Falling Particle Receiver System

(Ho et al., Sandia National Laboratories)



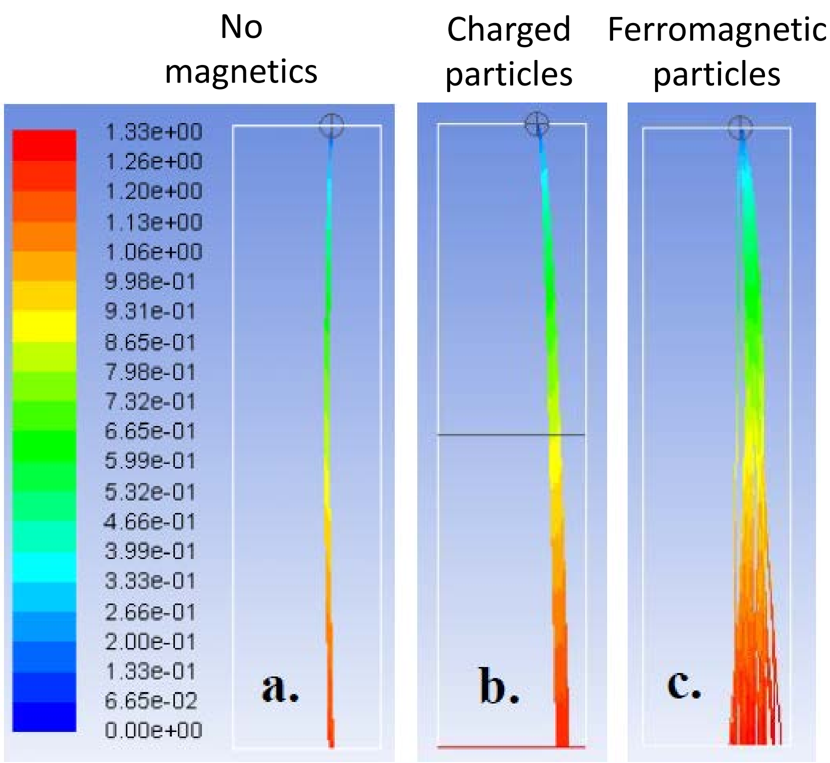


Over 300 suns on receiver
(June 25, 2015)

Staggered array of chevron-shaped meshes to obstruct flow (Pachinko). Up to 700 suns with bulk particle outlet temperatures > 700 C. Thermal efficiencies 70 – 80%.

Magnetic Field Flow Phenomena in a Falling Particle Receiver

(Armijo et al., Sandia National Laboratories)



Simulations of magnetic fields to control flow and residence time of ferromagnetic or charged particles in concentrated beam.

Receiver Categories

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- Dish Receivers

Test bench HEATREC for heat loss measurement on solar receiver tubes

(Marquez et al., CIEMAT PSA)

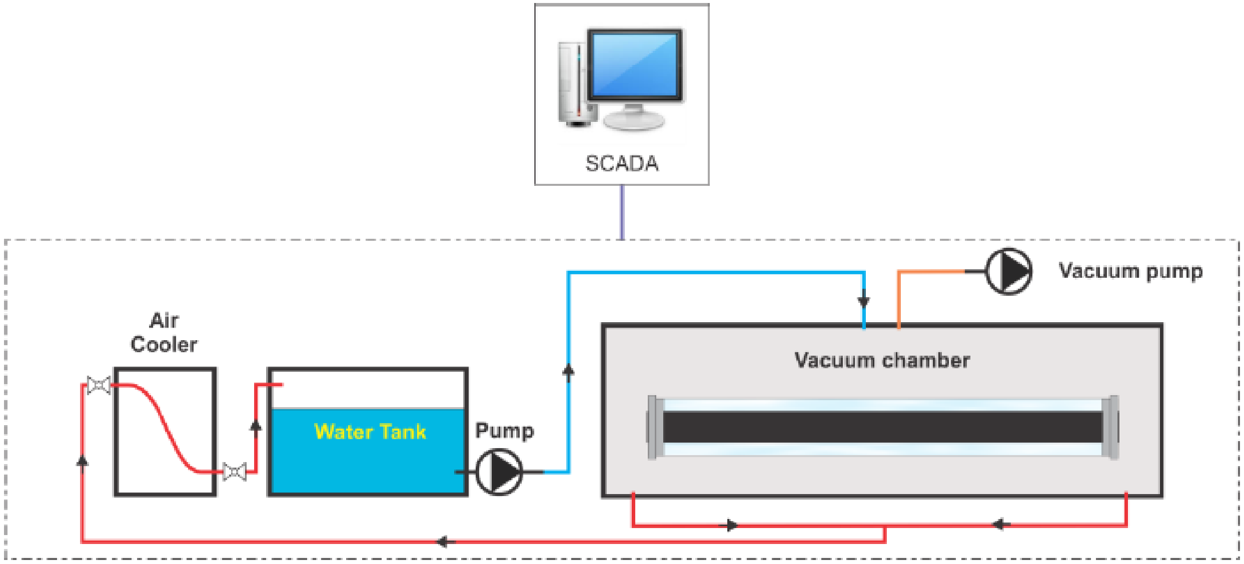
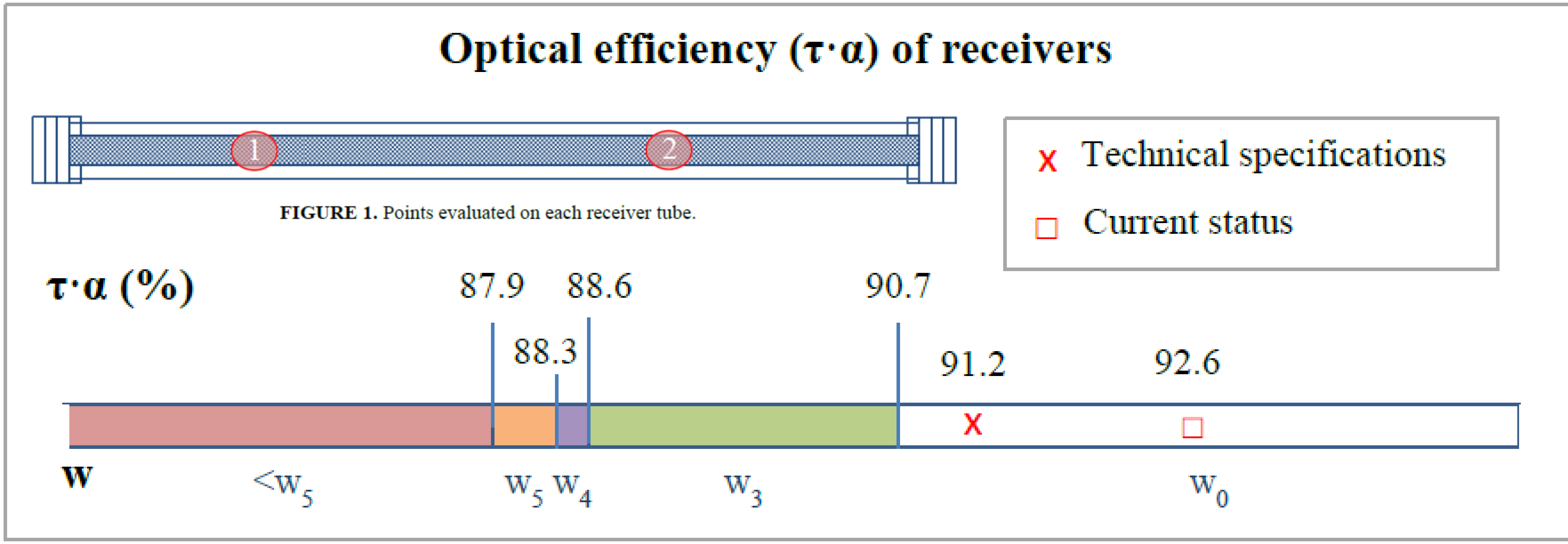


FIGURE 1. Scheme of the HEATREC test bench.

Test bench called HEATREC determines heat losses of receiver tubes under vacuum

Degradation of Receiver Tubes Performance After Four Years of Operation

(Espinosa-Rueda et al., Abengoa)

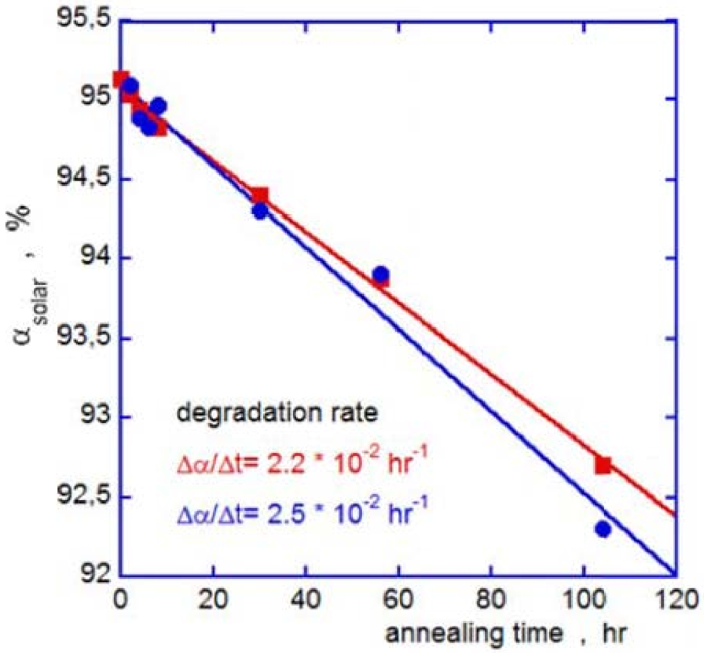


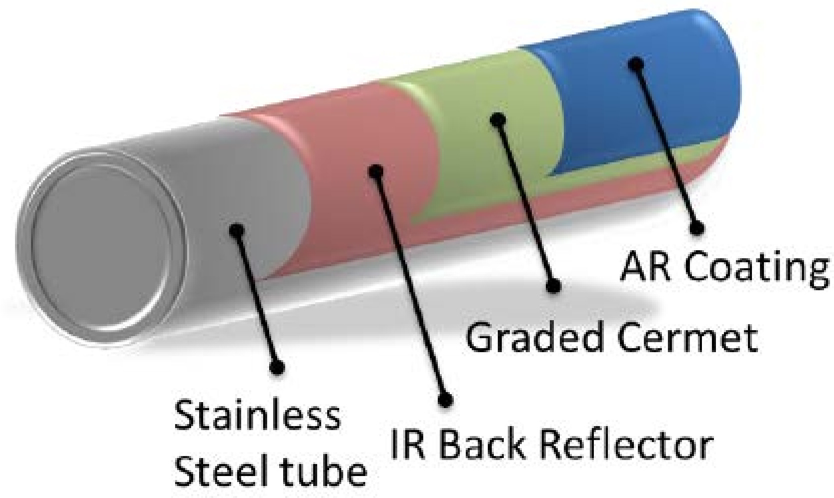
Trough receiver tubes and glass showed no degradation in absorptance and transmittance after 4 years of operation

Selective Absorber Coatings

Antonaia et al. (ENEA): Solar absorptance higher than 95% and emittance less than 13% at 550 C for molten salt operation with low degradation rate.

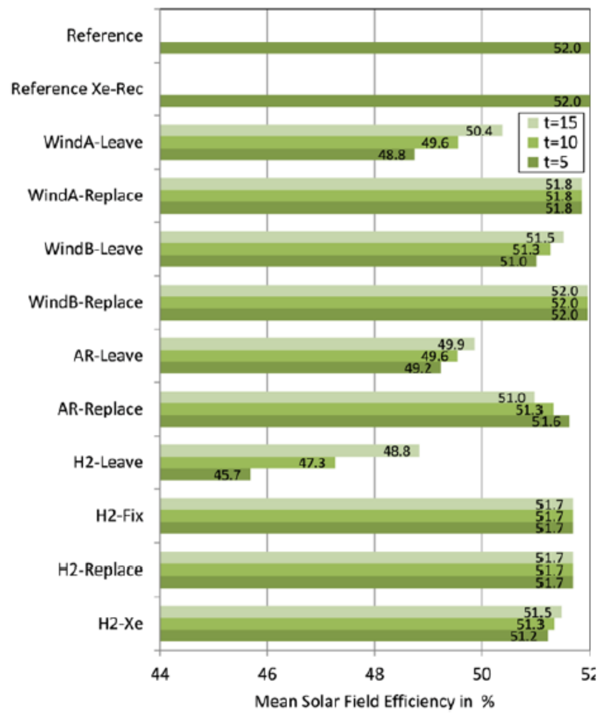
Chiarappa et al. (Archimede Solar Energy): LCOE Reduction for Parabolic Trough CSP: Innovative Solar Receiver with Improved Performance at Medium Temperature

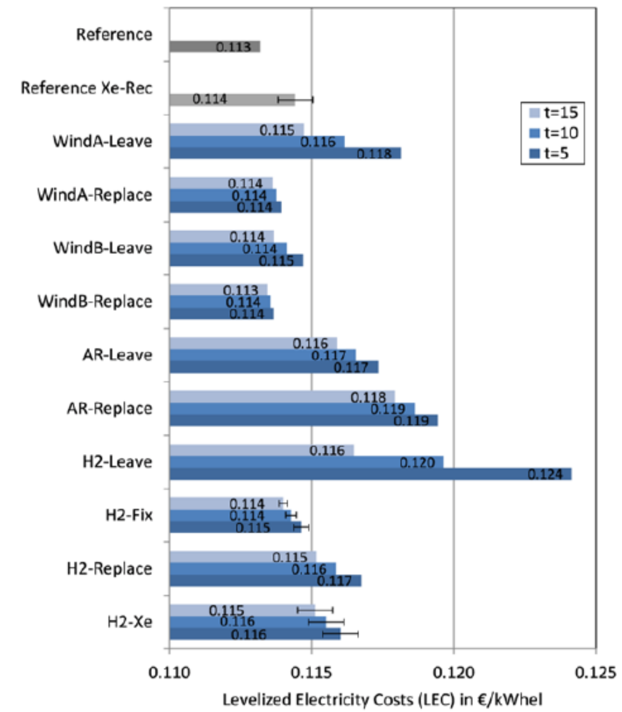




Techno-Economic Analysis of Receiver Replacement Scenarios in a Parabolic Trough Field

(Roger et al., DLR)

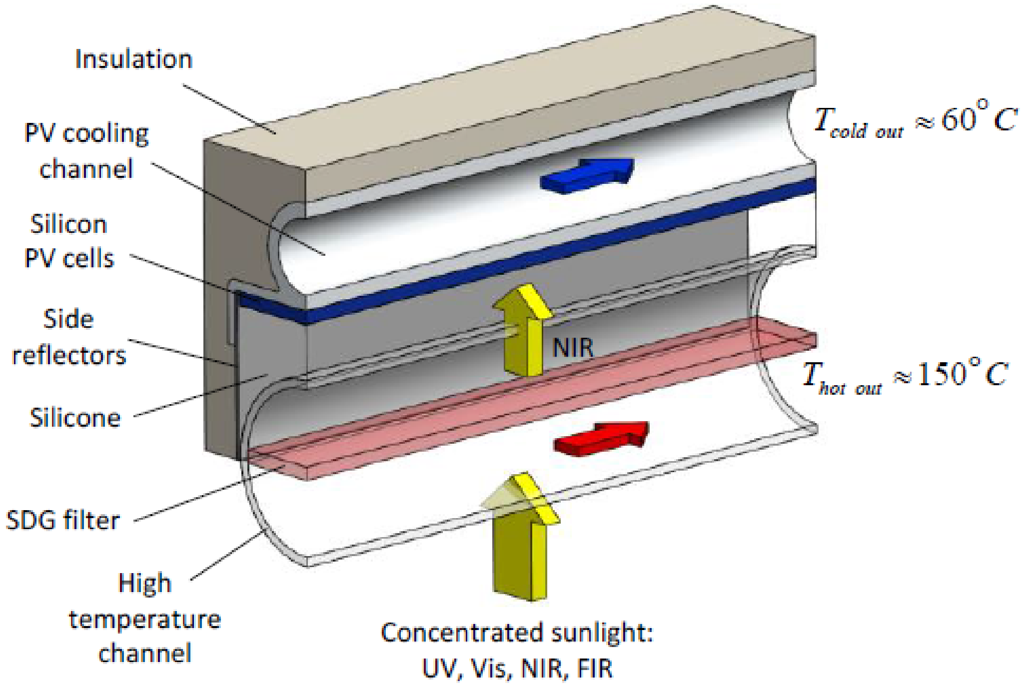




Investigated trough receiver loss mechanisms such as breakage and hydrogen production, and economic payback for replacement or repairs to minimize LCOE.

Experimental Performance Evaluation of a Hybrid CST Receiver for Linear Concentrators

(Stanley et al., RMIT University)



Experiments of splitting to convert solar energy to thermal energy (< 700 nm and > 1200 nm) with propylene glycol and to electricity (700 – 1200 nm) via silicon PV cells.

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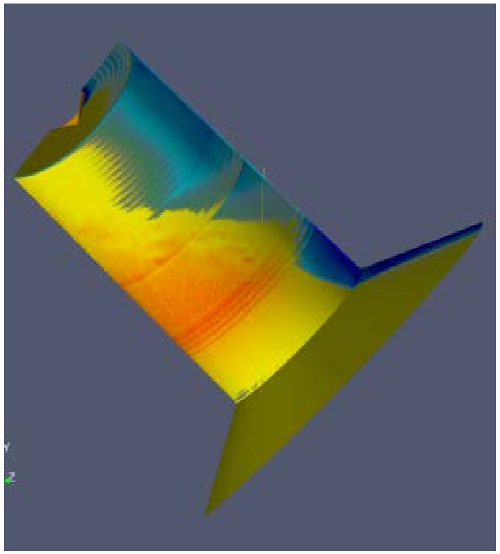
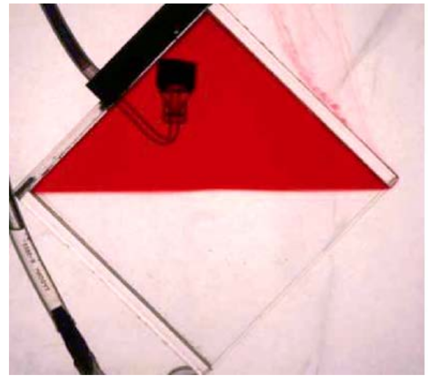
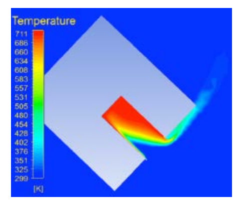
Reduction of Convective Losses in Solar Cavity Receivers

(Hughes et al., Australian National University)

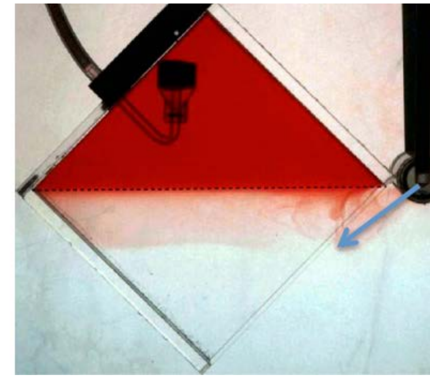


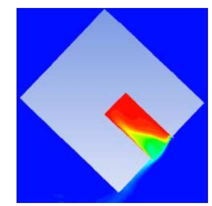
Recuperation from non-uniform temperatures





No air jet



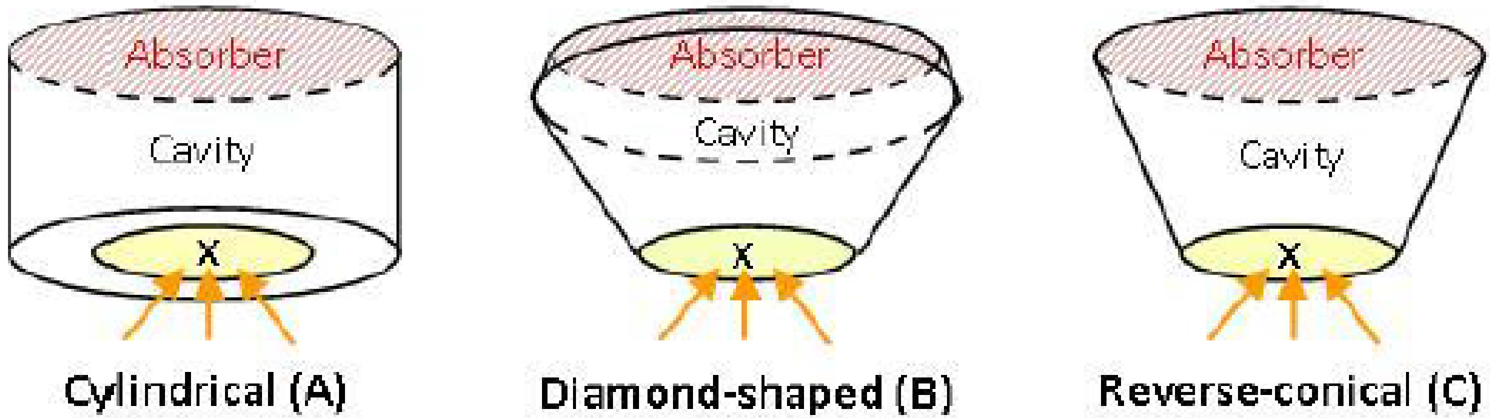


Air jet across aperture

Non-uniform temperatures in a cavity receiver can yield recuperation. Air jet across aperture can seal heat within cavity.

A Detailed Radiation Heat Transfer Study of a Dish-Stirling Receiver: the Impact of Cavity Wall Radiation Properties and Cavity

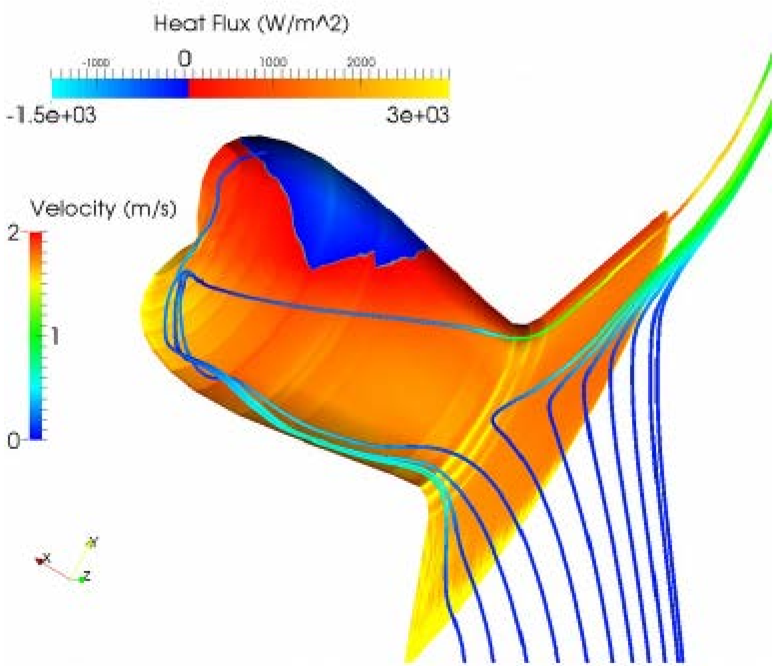
(Garrido et al., KTH Royal Institute of Technology)



Performed Monte-Carlo ray-tracing simulations to optimize dish receiver geometry. Reverse-conical was the best, although thermal efficiencies were similar.

Development of a Higher-Efficiency Tubular Cavity Receiver for Direct Steam Generation on a Dish Concentrator

(Pye et al., Australian National University)

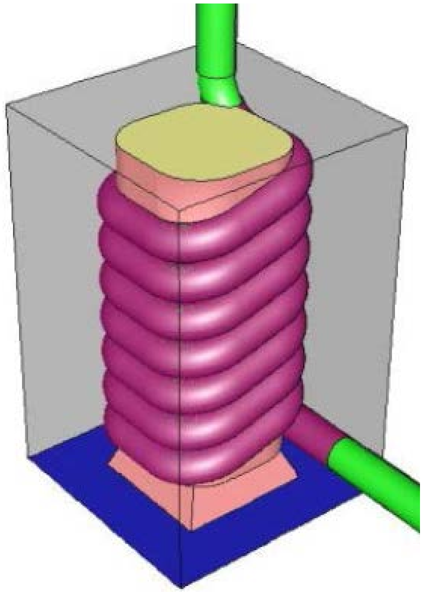


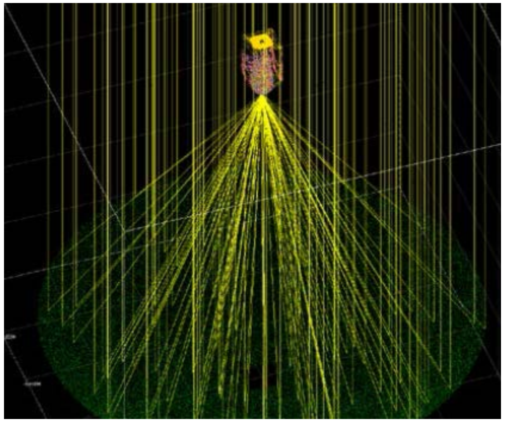
(b) inlet temperature 250 °C

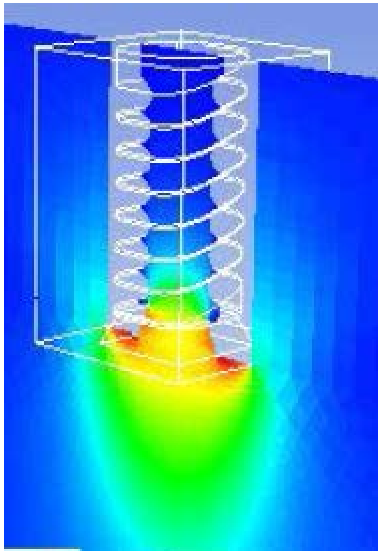
Optimized helical wound tubular dish receiver for heating steam from 60 – 500 C with 98.7% efficiency.

Combining Ray Tracing and CFD in the Thermal Analysis of a Parabolic Dish Tubular Cavity Receiver

(Craig et al., University of Pretoria)







Ray-tracing/CFD coupling for optical and conjugate heat transfer of air flow through complex tubular receiver.

High Performance Felt-Metal-Wick Heat Pipe for Solar Receivers

(Andraka et al., Sandia National Labs)

Testing of felt-metal-wicks revealed blended multi-size felt fibers showed good performance and durability for heat pipe receivers. Applications include dish-Stirling and sCO2 systems where isothermal or small ΔT is needed.

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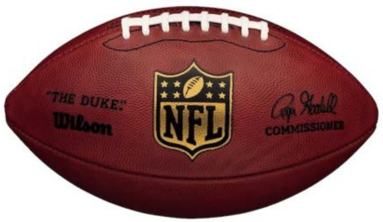
Conclusions

- ~50 thermal receiver papers submitted
  - 34 on tower receivers
    - Tubular/cavity and volumetric air (85%)
    - Particle receivers gaining more attention (15%)
  - 16 on trough / line-focus receivers
  - 10 on dish receivers
- Focus on mitigating convective and radiative heat losses
  - Novel volumetric heating designs (not necessarily air-based)
    - Tubular layout optimization; spiky receivers; fractal-like features
- Characterization and modeling of receiver performance still important

Why do football coaches love CSP engineers?



- Because we make great receivers!