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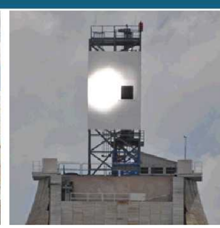
Optical Ray-Tracing Performance Modeling of Quartz Half-Shell Tubes Aperture Cover for Falling Particle Receiver (ES2019-3927)



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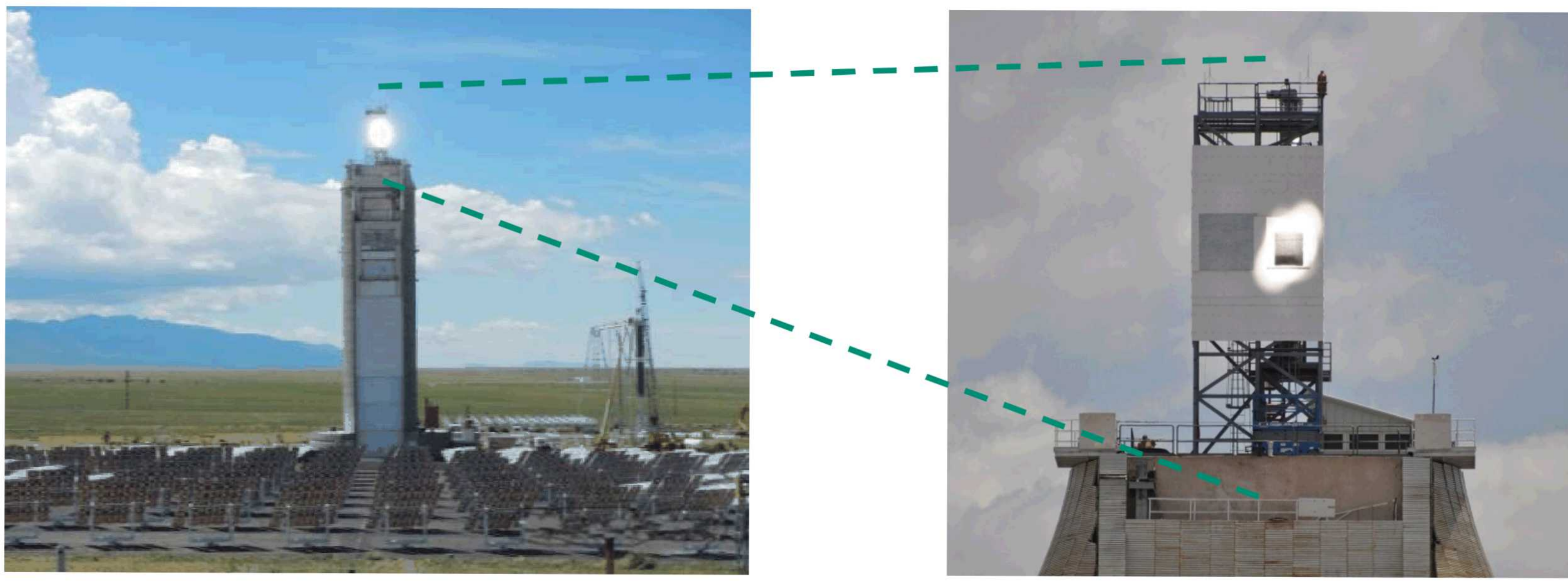
Outline

- Background
- Motivation
- Optical Modeling
- Results
- Conclusions

Background

- 1 MW falling particle receiver (FPR) was design and built and is currently being evaluated at Sandia National Solar Thermal Test Facility (NSTTF).
- The prototype system has a 1 m^2 aperture.



- Falling particle receivers are one of the Gen3 pathway receivers.

Motivation

- Two concerns for FPR are potential particle and thermal losses through the aperture.
- An aperture hood can potentially reduce wind impacts and particle losses through the aperture. The aperture also provided the support structure for the quartz half-shell tubes (QHST).
- QHST can further reduce particle losses and also reduce thermal losses through the aperture.
- This work evaluated optical performance impacts (through modeling) from adding an aperture hood and quartz glass half-shell tubes to the receiver aperture on the prototype system.

- The results from this study can be used as boundary conditions for thermal analysis.
- Combination of the optical and thermal analyses can result in an optimum receiver configuration for high thermal efficiencies.

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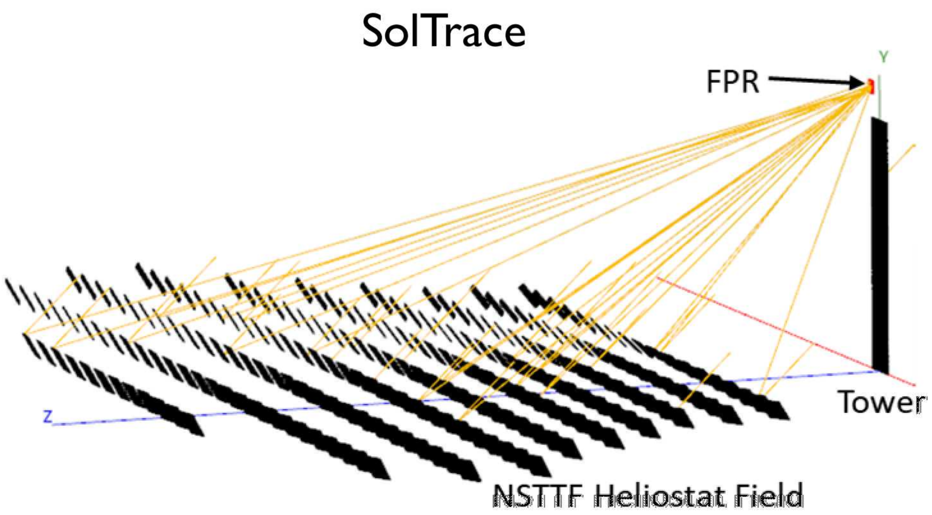
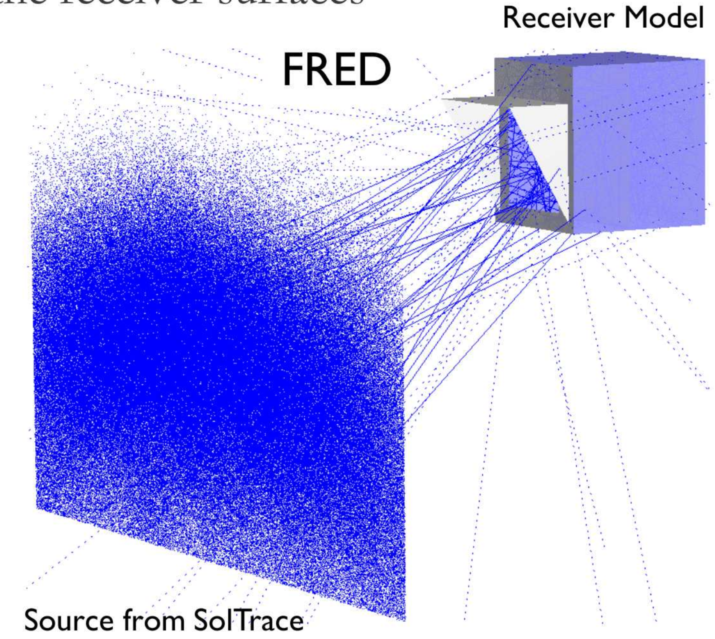
Optical Modeling Approach

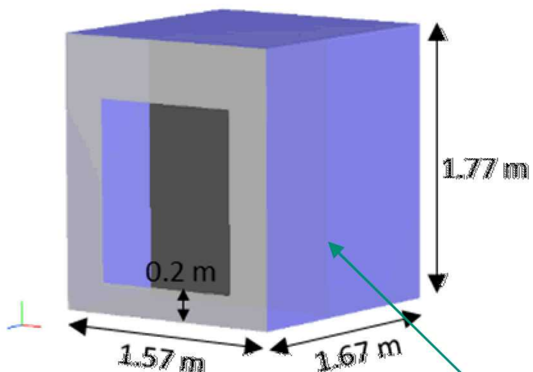
- Evaluation by modeling and simulations only
- Used SolTrace and FRED optical modeling tools
  - SolTrace was used to set up the NSTTF field and sunshape → input radiation to the receiver, which was incorporated into FRED
  - FRED was used to model the receiver including the particle curtain and quartz half-shell tubes and evaluate the optical performance of the receiver in various configurations
  - FRED calculated the net irradiance incident on the receiver surfaces





Optical Modeling of Receiver

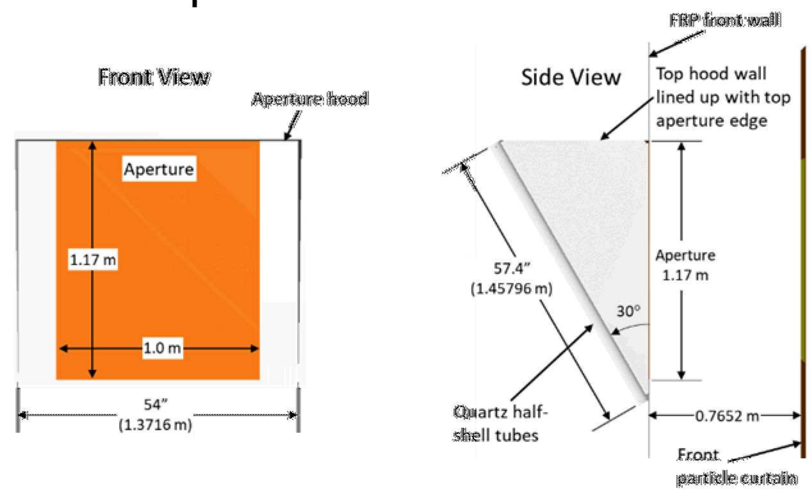
Baseline Receiver Model



RSLE
- ρ ~ 0.9 in pristine condition
- ρ ~ 0.5 in soiled condition (assumed)

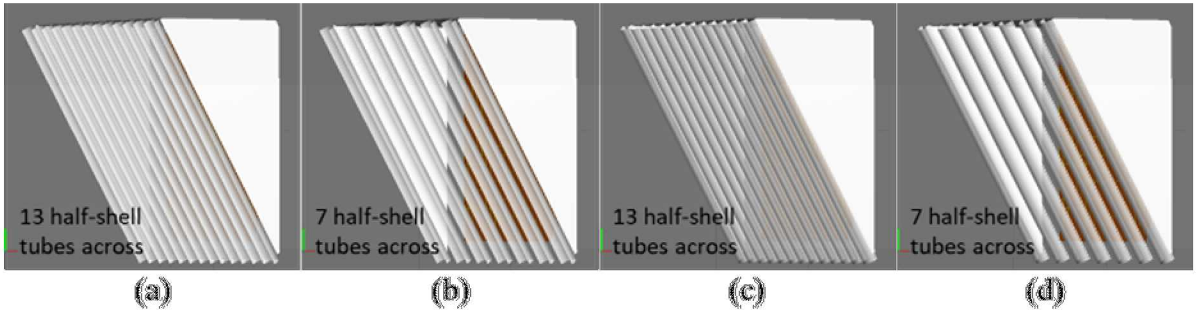
Particle curtain modeled as a thin diffuse surface

Aperture Hood Model



Quartz Half-Shell Tubes Arrangements

Quartz glass tubes cut in half lengthwise
- Length = 1.46 m
- OD = 110 mm
- ID = 105 mm



Optical Parameters

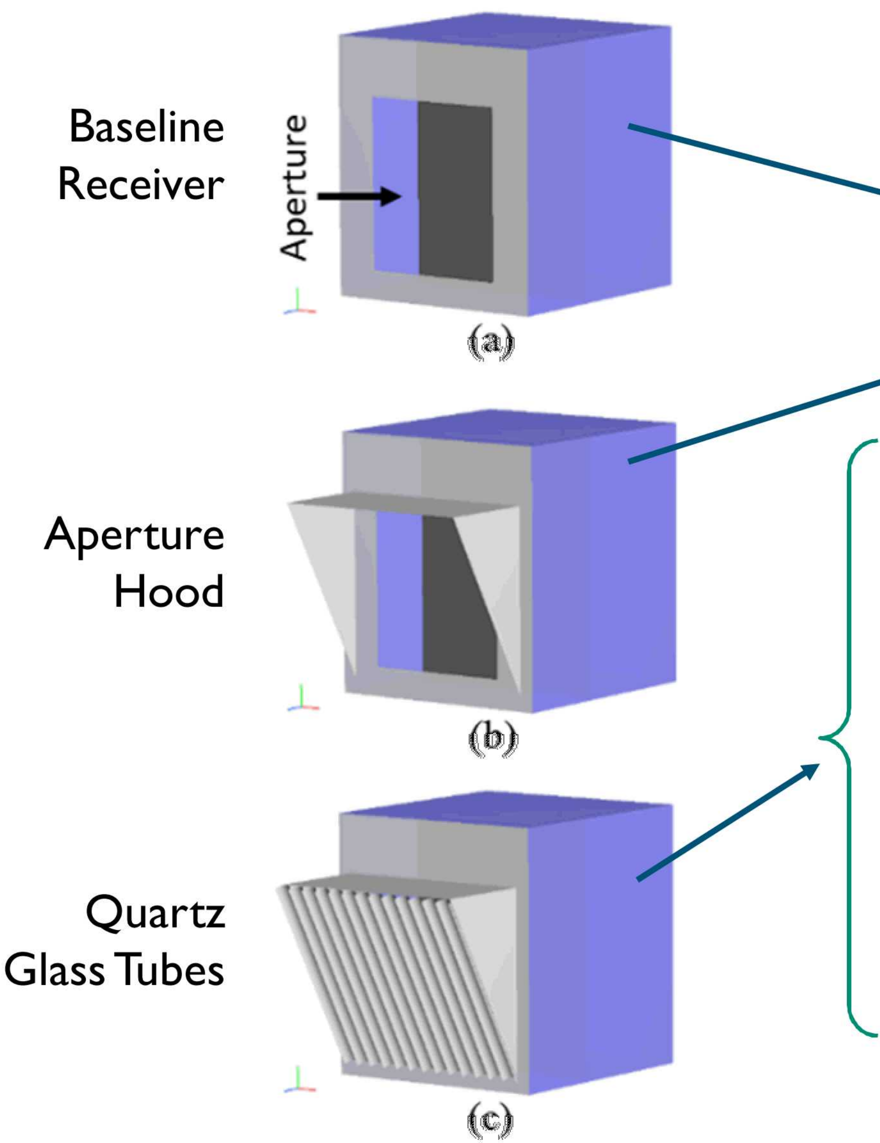


TABLE 1: Summary of the modeling and simulation matrix.

Receiver Config.	Aperture Cover Configuration	Walls Reflectance, ρ	Particle Curtain α, ρ, τ
1	Baseline (no hood, no QHST)	0.9 (bottom wall) 0.9 (all other walls)	0.5, 0.1, 0.4 0.8, 0.1, 0.1
		0.1 (bottom wall) 0.5 (all other walls)	0.5, 0.1, 0.4 0.8, 0.1, 0.1
2	Hood only	0.9 (bottom wall) 0.9 (all other walls)	0.5, 0.1, 0.4 0.8, 0.1, 0.1
		0.1 (bottom wall) 0.5 (all other walls)	0.5, 0.1, 0.4 0.8, 0.1, 0.1
3	Hood + QHST concave out, no spacing	0.9 (bottom wall) 0.9 (all other walls)	0.5, 0.1, 0.4 0.8, 0.1, 0.1
		0.1 (bottom wall) 0.5 (all other walls)	0.5, 0.1, 0.4 0.8, 0.1, 0.1
4	Hood + QHST concave out, high spacing	0.9 (bottom wall) 0.9 (all other walls)	0.5, 0.1, 0.4 0.8, 0.1, 0.1
		0.1 (bottom wall) 0.5 (all other walls)	0.5, 0.1, 0.4 0.8, 0.1, 0.1
5	Hood + QHST concave out, no spacing	0.9 (bottom wall) 0.9 (all other walls)	0.5, 0.1, 0.4 0.8, 0.1, 0.1
		0.1 (bottom wall) 0.5 (all other walls)	0.5, 0.1, 0.4 0.8, 0.1, 0.1
6	Hood + QHST concave out, high spacing	0.9 (bottom wall) 0.9 (all other walls)	0.5, 0.1, 0.4 0.8, 0.1, 0.1
		0.1 (bottom wall) 0.5 (all other walls)	0.5, 0.1, 0.4 0.8, 0.1, 0.1

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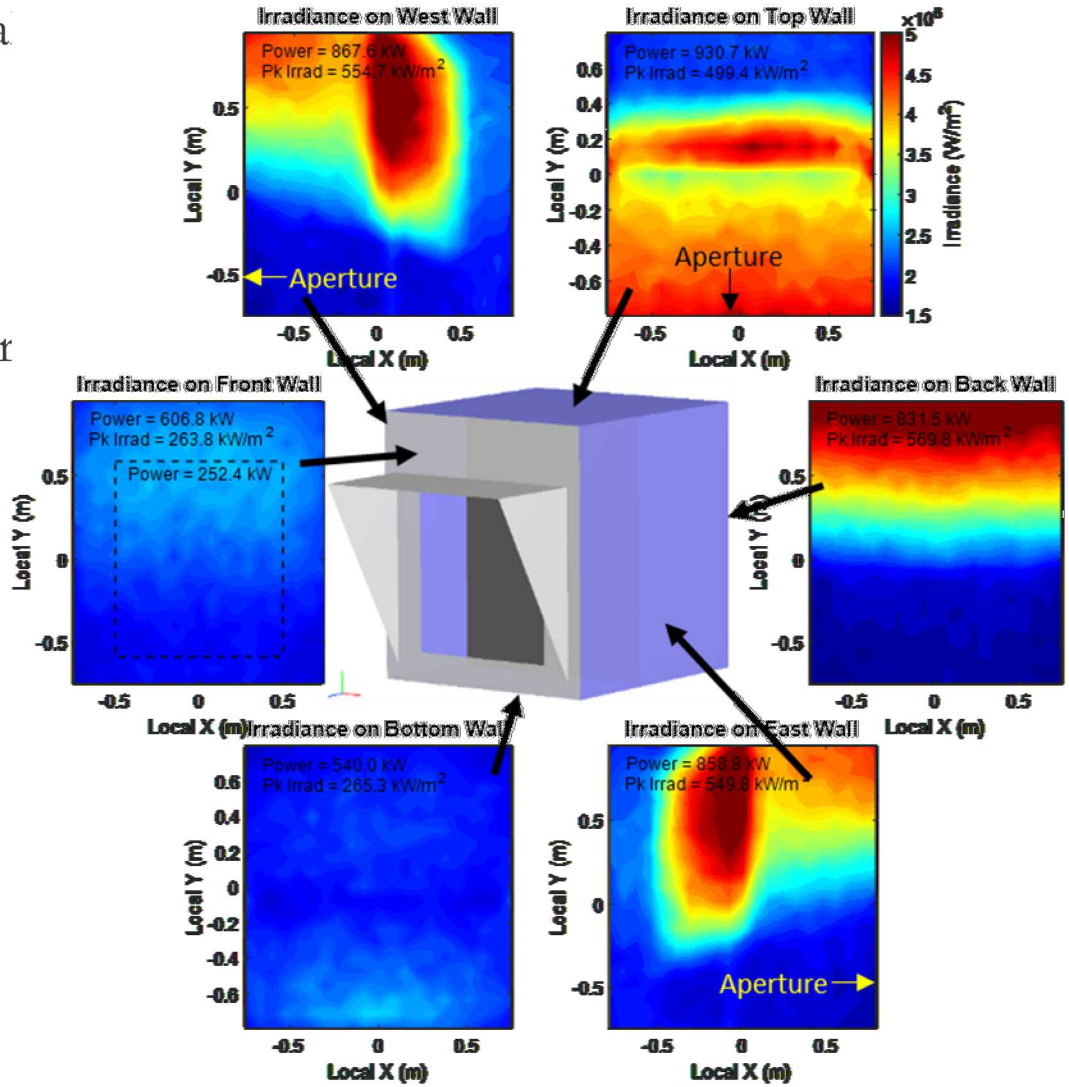
Results

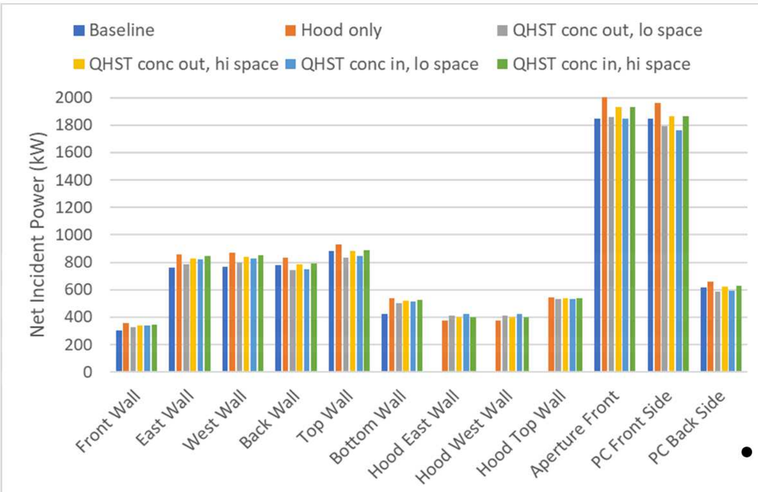
Example of Irradiance Maps on Internal Receiver Walls

- Light rays were collected on a the internal walls and particle curtain surfaces.
- Multiple reflections off and transmissions through any interacting optical surface wer allowed.



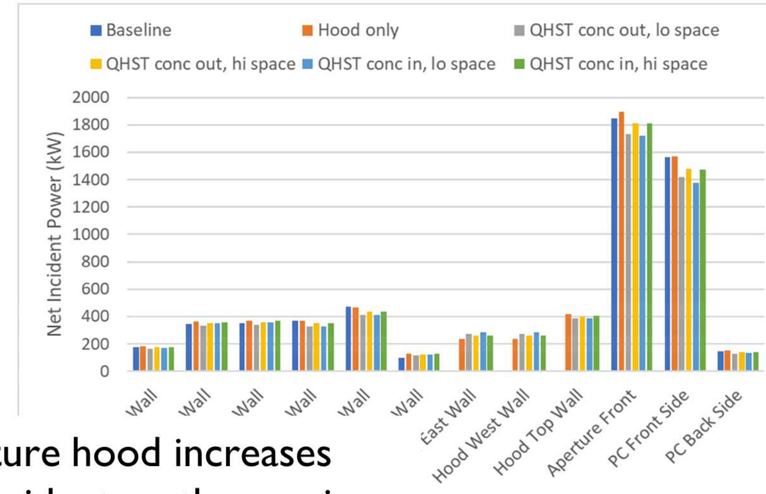
Net Incident Power on Internal Walls & Particle Curtain

All the walls have ρ = 0.9.

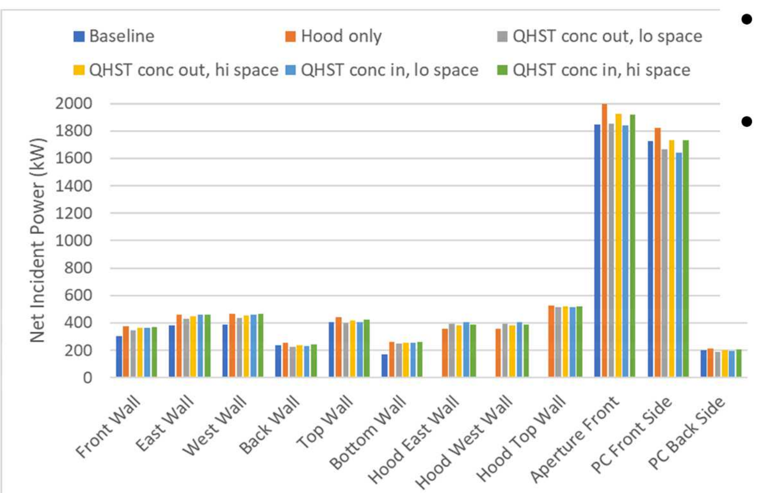


Particle curtain: α=0.8, ρ=0.1, τ=0.1

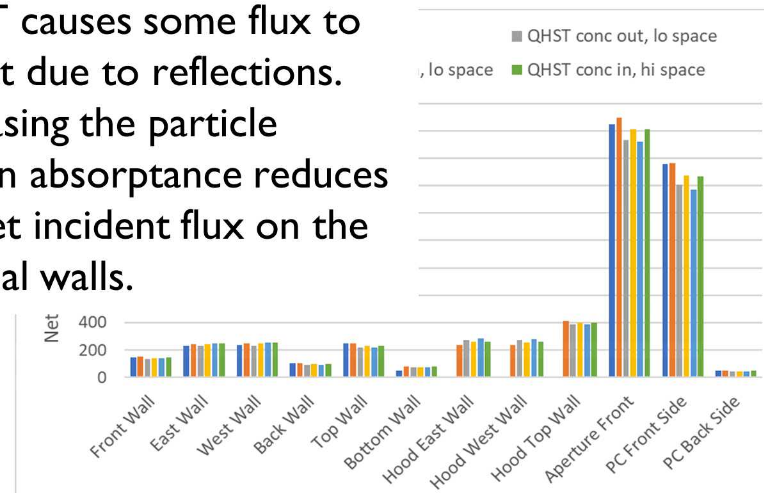
The bottom wall has ρ = 0.1 and all other walls have ρ = 0.5.



0.8, ρ=0.1, τ=0.1



Particle curtain: α=0.5, ρ=0.1, τ=0.4.



Particle curtain: α=0.5, ρ=0.1, τ=0.4.

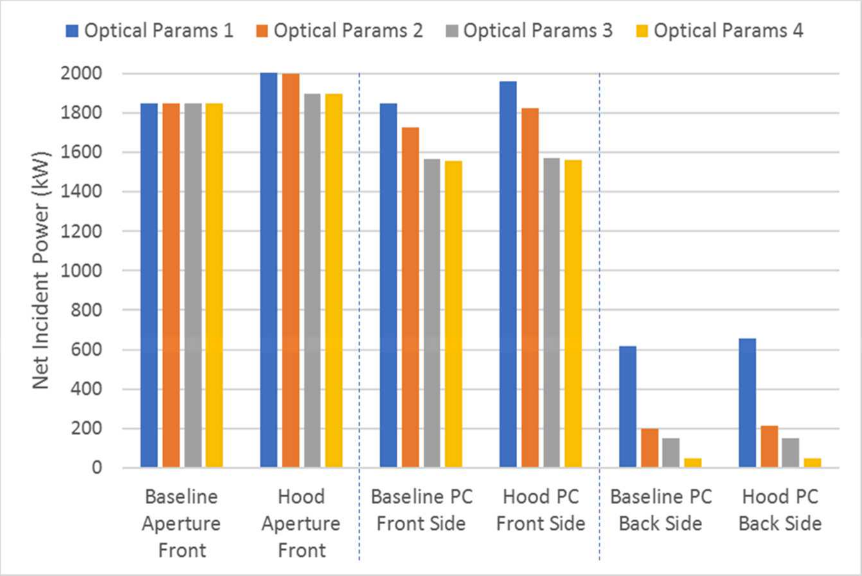
- Aperture hood increases flux incident on the receiver aperture.
- QHST causes some flux to be lost due to reflections.
- Increasing the particle curtain absorptance reduces the net incident flux on the internal walls.

Impacts of Aperture Hood

- When the aperture hood reflectance is high (≥ 0.9), more of the incident radiation is reflected into the aperture, which otherwise would have been lost as spillage.
  - ~8% increase in the flux on the aperture
  - ~6% increase in flux on the particle curtain
- When the wall reflectance is low (≤ 0.5), flux increase on the receiver was small (~2%)

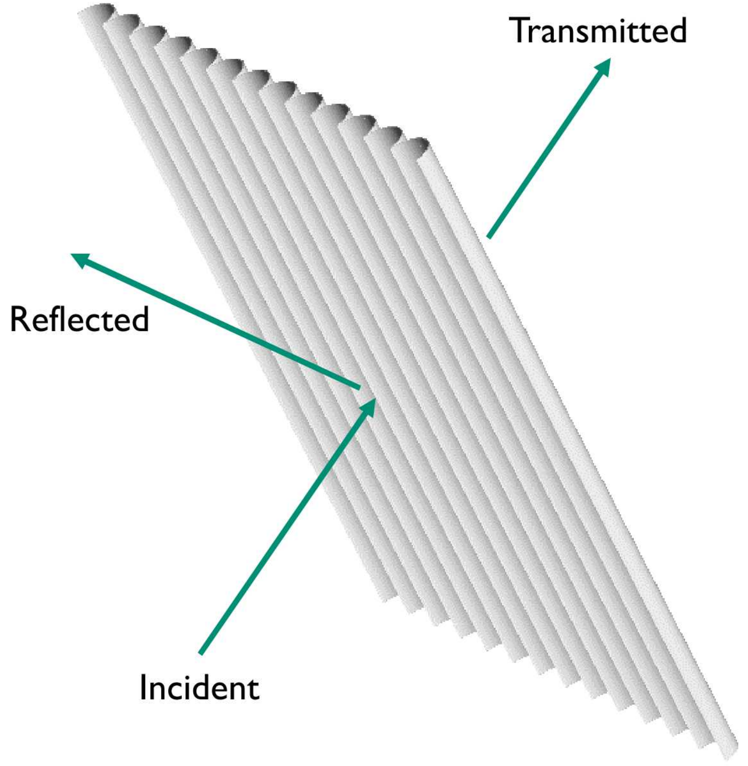
TABLE 2: Optical parameters group definition.

Optical Parameters Group	Wall Reflectance	Particle Curtain Optical Properties
Optical Parameters 1	0.9 (bottom wall) 0.9 (all other walls)	α=0.5, ρ=0.1, τ=0.4
Optical Parameters 2	0.9 (bottom wall) 0.9 (all other walls)	α=0.8, ρ=0.1, τ=0.1
Optical Parameters 3	0.1 (bottom wall) 0.5 (all other walls)	α=0.5, ρ=0.1, τ=0.4
Optical Parameters 4	0.1 (bottom wall) 0.5 (all other walls)	α=0.8, ρ=0.1, τ=0.1



Impacts of QHST Curvature Direction

- Using detector surfaces in FRED the reflected and transmitted light at the quartz half-shell tube array were measured.
- With no spacing between the tubes, 6-7% of the light was reflected.
- With spacing between the tubes, ~3% of the light was reflected.
- There no significant advantages observed for QHST concave in or out.
  - Concave out was slightly better (< 1%) at reducing reflections of the incident light.



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Conclusions

- Two concerns for falling particle receivers are potential particle and heat losses through the aperture.
  1. An aperture hood, which could reduce wind impacts and particle losses, was optically evaluated.
  2. Quartz glass half-shell tubes, which could further reduce particle losses and also reduce thermal losses, were also optically evaluated.

- Aperture with a hood increases the flux incident on the receiver aperture and the particle curtain.
- Some of the incident light is lost when quartz glass half-shell tubes were installed due to reflections.
- Direction of the curved tubes did not show significant differences; concave out orientation was slightly better.

Questions?

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