Workshop

Workshop on Renewable Energies and Energy Efficiency in water treatments

EERES4WATER Project (EAPA_1058/2018)

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Assessment of the integration of a MED-TVC plant into a solar tower with Brayton cycle

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Contents

Motivation

- **SOLTERMIN** Project ("*Solar thermal solutions for integration in industrial processes*"), funded by Spanish Government Call RETOS 2017 (ENE2017-83973-R). Duration: 4 years

- **Objective**: development of compact and optimized solutions of concentrated solar thermal energy technologies suitable for ***supplying heat in industrial processes***

- ⇒ **Subtask 4.3** : **Analysis of a hybrid solar mini-tower + Brayton cycle + multi-effect distillation unit**

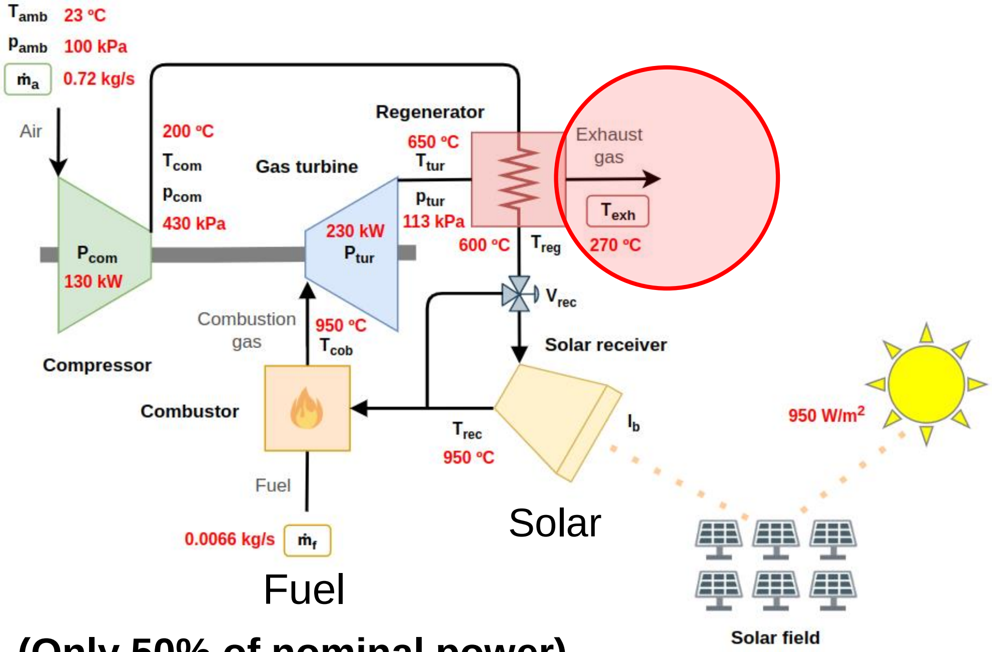
  - Non-consumption of water by the power cycle
  - Capacity to integrate high T desalination systems (more efficient), no penalization of power cycle eficiency
  - High modularity and capability of developing small power systems for areas with water scarcity

Contents

System description

- The system proposed is based on the **AORA Solar Central Receiver tower** system located at Plataforma Solar de Almería

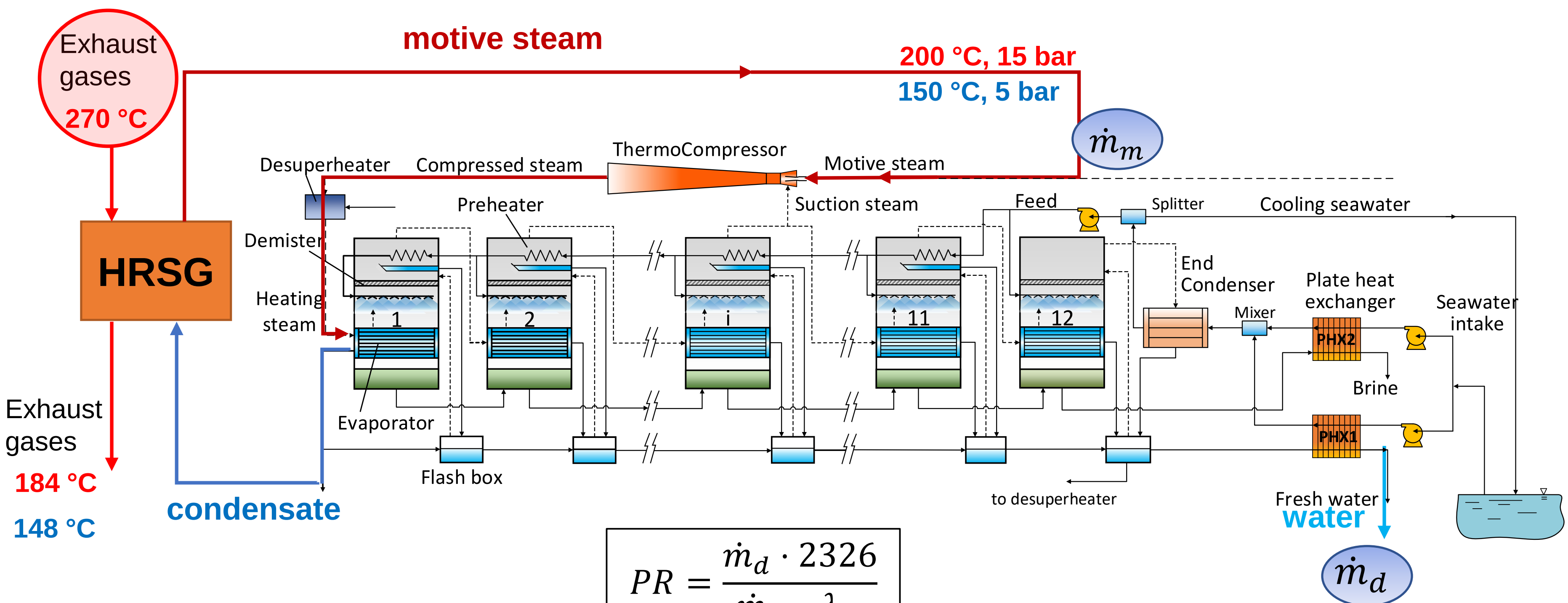
- 100 kW hybrid solar/gas turbine. 52 heliostats. Tower height: 30 m



(Only 50% of nominal power)

System description

- Exahust gases from Brayton cycle are directed to a **heat recovery steam generator** (HRSG) where steam is generated to drive the **MED-TVC** unit

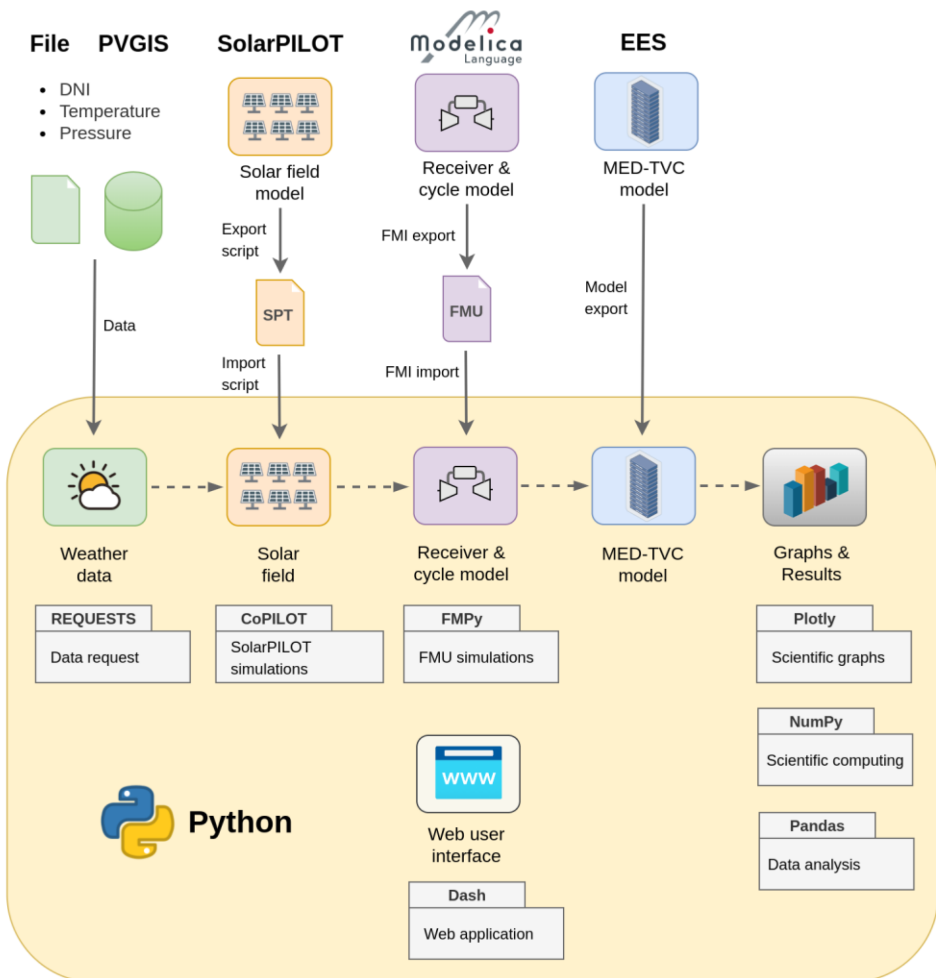


$$PR = \frac{\dot{m}_d \cdot 2326}{\dot{m}_m \cdot \lambda_m}$$

Contents

- Motivation
- System description
- ☛ Methods
- Results & Discussion
- Conclusions

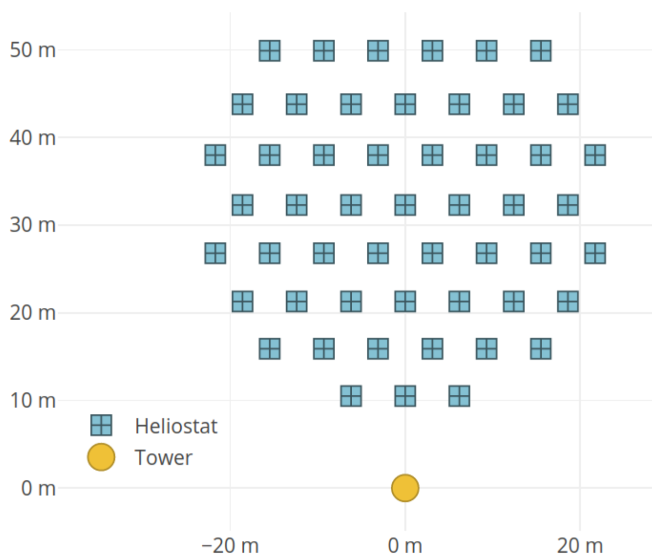
Methods



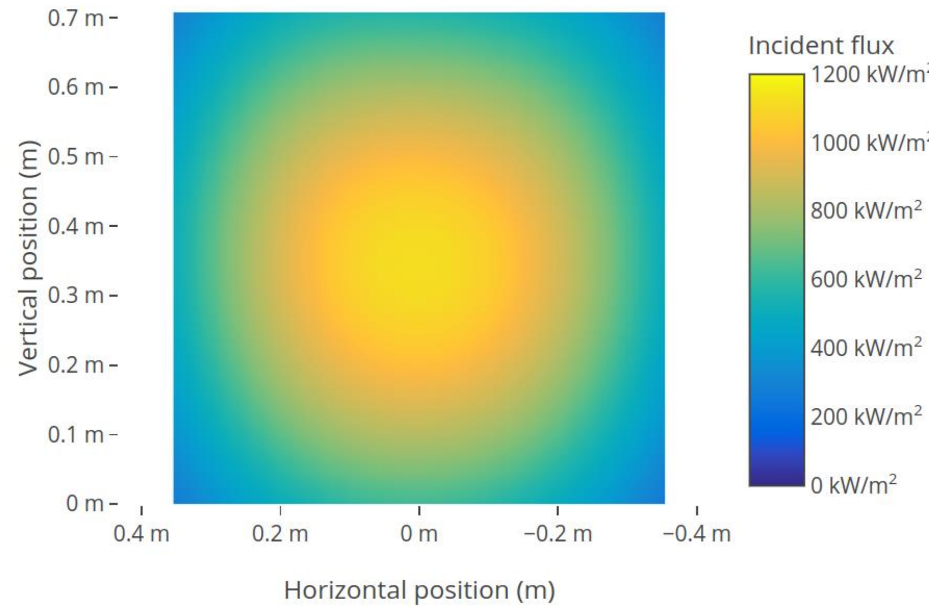
- Simulation structure:
  - Input weather data (PVGIS)
  - Solar field model (SolarPilot)
  - Receiver & Brayton cycle model (Modelica)
  - MED-TVC model (EES)
- Python has been used to integrate all the models and add a **GUI**, which allows to perform the simulations and generate the results
- The **MED-TVC model** has not been yet integrated

Methods

- **Solar Field model**
  - The SolarPILOT tool from NREL was used to model the **heliostat field**
  - It can determine hourly distribution of **concentrated solar irradiance** onto the receiver

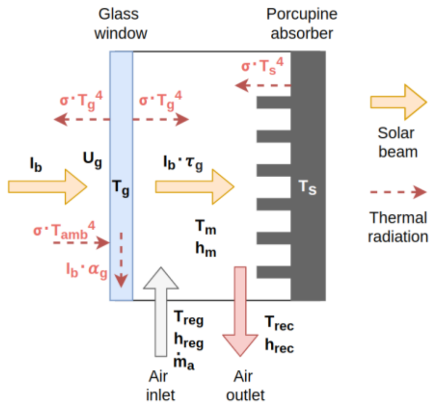


Heliostats layout



Methods

- **Receiver and Brayton cycle models (Modelica)**



Compressor

$$\gamma_{com} = \frac{c_{p,com}}{c_{v,com}}$$

$$x_{com} = \left(PR_{com} \cdot \frac{\dot{m}_a}{\dot{m}_{a,n}}\right)^{\frac{\gamma_{com}-1}{\gamma_{com}}}$$

$$T_{com} = T_{amb} \cdot \left(1 + \frac{x_{com}-1}{\eta_{com}}\right)$$

$$p_{com} = p_{amb} \cdot PR_{com}$$

$$P_{com} = \dot{m}_a \cdot c_{p,com} \cdot (T_{com} - T_{amb})$$

Gas Turbine

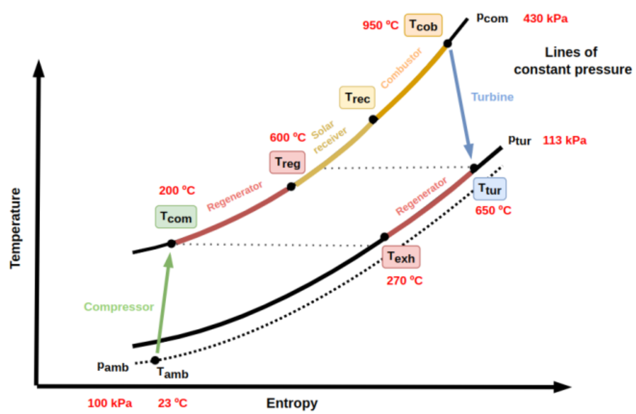
$$\gamma_{tur} = \frac{c_{p,tur}}{c_{v,tur}} \qquad p_{tur} = \frac{p_{com}}{PR_{tur}}$$

$$x_{tur} = \left(PR_{tur} \cdot \frac{\dot{m}_f + \dot{m}_a}{\dot{m}_{f,n} + \dot{m}_{a,n}}\right)^{\frac{\gamma_{tur}-1}{\gamma_{tur}}}$$

$$T_{tur} = T_{cob} \cdot \left(1 - \eta_{tur} \cdot \left(1 - \frac{1}{x_{tur}}\right)\right)$$

$$P_{tur} = (\dot{m}_a + \dot{m}_f) \cdot c_{p,tur} \cdot (T_{cob} - T_{tur})$$

$$P_{net} = P_{tur} - P_{com}$$



Glass Window

$$I_b \cdot \alpha_g + \sigma \cdot (T_{amb}^4 + T_s^4 - 2 \cdot T_g^4) = U_g \cdot (T_g - T_{reg})$$

Absorber

$$G = \frac{I_b \cdot \tau_g + \sigma(T_g^4 - T_s^4)}{h_{rec} - h_m}$$

$$G = \frac{\dot{m}_a}{A_s} \qquad T_s = \frac{T_{reg} + T_m}{2}$$

Cavity

$$h_m - h_{reg} = \frac{U_g \cdot (T_g - T_{reg})}{G}$$

Regenerator

$$T_{reg} = T_{com} \cdot \frac{c_{p,com}}{c_{p,reg}} + \frac{\eta_{reg}}{c_{p,reg}} \cdot (T_{tur} \cdot c_{p,tur} - T_{com} \cdot c_{p,com})$$

$$T_{exh} = T_{tur} \cdot \frac{c_{p,tur}}{c_{p,exh}} - \frac{\eta_{reg}}{c_{p,exh}} \cdot (T_{tur} \cdot c_{p,tur} - T_{com} \cdot c_{p,com})$$

Combustor

$$T_{cob} = T_{rec} + \frac{\eta_{cob} \cdot LHV}{c_{p,cob}} \cdot \frac{\dot{m}_f}{\dot{m}_a + \dot{m}_f}$$

Methods

- **MED-TVC model**
  - A first-principles model has been implemented in **Engineering Equation Solver (EES)**
  - ***Polynomial equations*** have been obtained by performing simulations using the MED-TVC operation model
  - The results from the simulations have been fitted by the Matlab tool MultiPolyRegress

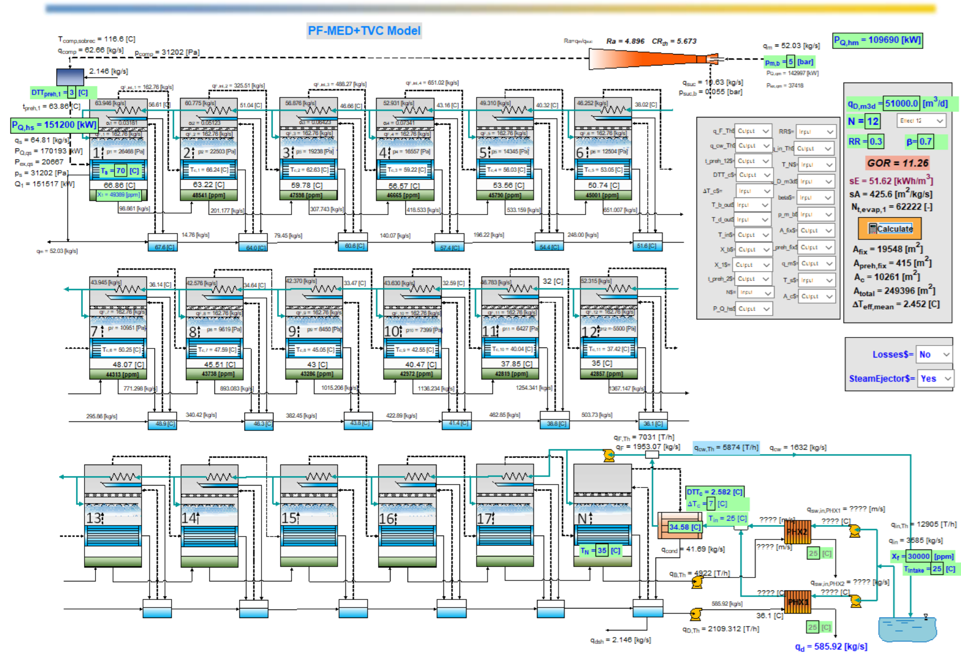
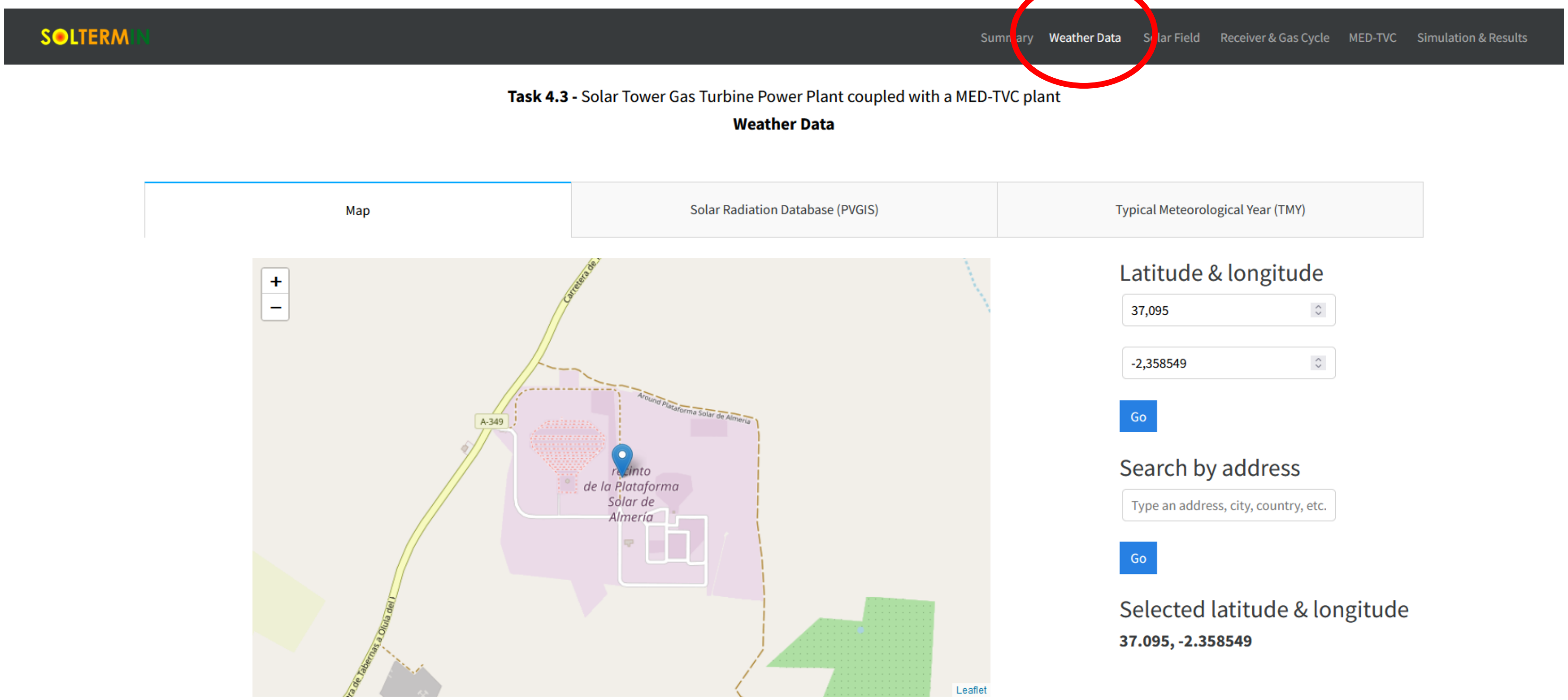


Table 1

1..27	$P_{m,b}$ [bar]	$q_{D,m3d}$ [m3/d]	T_{intake} [C]	RR	X_f [ppm]	$q_{F,m3h}$ [m3/h]	$q_{cw,m3h}$ [m3/h]	q_s [kg/s]	q_{suc} [kg/s]	q_m [kg/s]	Ra	CR_{th}	GOR	$\Delta T_{eff,mean}$ [C]	A_{fix} [m2]	$A_{preh,fix}$ [m2]	A_c [m2]
Run 1	45	100000.0	25	0.3	30000	13543	12651	171.3	61.85	103.6	1.675	4.452	11.09	3.264	43665	1267	21193
Run 2	45	100000.0	25	0.3	45000	13395	13199	171.1	61.22	103.9	1.698	4.514	11.05	3.012	47312	1251	22582
Run 3	45	100000.0	25	0.3	60000	13249	13762	170.8	60.52	104.3	1.724	4.582	11.01	2.732	52129	1237	24349
Run 4	45	100000.0	25	0.35	30000	11608	14839	168.3	60.66	101.8	1.678	4.461	11.28	3.224	44416	1085	21568
Run 5	45	100000.0	25	0.35	45000	11481	15370	168	60	102.2	1.703	4.529	11.24	2.945	48614	1073	23128
Run 6	45	100000.0	25	0.35	60000	11356	15919	167.8	59.25	102.7	1.733	4.605	11.19	2.634	54331	1062	25157
Run 7	45	100000.0	25	0.4	30000	10157	16480	165.9	59.73	100.5	1.682	4.472	11.43	3.176	45248	949.1	21932
Run 8	45	100000.0	25	0.4	45000	10046	17006	165.7	59.02	100.9	1.710	4.547	11.38	2.864	50163	939.4	23710
Run 9	45	100000.0	25	0.4	60000	9937	17553	165.5	58.2	101.5	1.744	4.633	11.32	2.514	57115	930.9	26089
Run 10	45	100000.0	30	0.3	30000	13545	9832	168.4	68.83	94.19	1.368	3.394	12.17	2.632	53793	1153	18787
Run 11	45	100000.0	30	0.3	45000	13397	10297	168.2	68.37	94.43	1.381	3.441	12.14	2.377	59565	1141	20047
Run 12	45	100000.0	30	0.3	60000	13252	10767	168	67.88	94.69	1.395	3.493	12.11	2.093	67599	1129	21657
Run 13	45	100000.0	30	0.35	30000	11610	12094	165.5	67.61	92.64	1.370	3.401	12.38	2.592	54816	988	19208
Run 14	45	100000.0	30	0.35	45000	11483	12537	165.4	67.13	92.92	1.384	3.452	12.34	2.309	61510	978.3	20630
Run 15	45	100000.0	30	0.35	60000	11359	12985	165.2	66.61	93.23	1.400	3.51	12.3	1.994	71195	969.8	22488
Run 16	45	100000.0	30	0.4	30000	10158	13791	163.4	66.66	91.49	1.372	3.409	12.53	2.544	56000	864.8	19602
Run 17	45	100000.0	30	0.4	45000	10048	14221	163.2	66.15	91.81	1.388	3.466	12.49	2.229	63913	857.4	21227
Run 18	45	100000.0	30	0.4	60000	9939	14658	163.1	65.59	92.17	1.405	3.531	12.44	1.875	75944	851.1	23417
Run 19	45	100000.0	35	0.3	30000	13547	6952	165.4	75.88	84.68	1.116	2.612	13.52	2.001	70334	1022	16365
Run 20	45	100000.0	35	0.3	45000	13399	7433	165.3	75.28	85.1	1.130	2.648	13.45	1.741	80785	1013	17564
Run 21	45	100000.0	35	0.3	60000	13255	7923	165.1	74.64	85.55	1.146	2.689	13.38	1.454	96707	1006	19101
Run 22	45	100000.0	35	0.35	30000	11612	9301	162.8	74.59	83.4	1.118	2.617	13.72	1.961	71942	876.5	16841
Run 23	45	100000.0	35	0.35	45000	11485	9762	162.7	73.96	83.87	1.134	2.657	13.65	1.674	84228	870	18197
Run 24	45	100000.0	35	0.35	60000	11362	10234	162.5	73.29	84.37	1.151	2.702	13.57	1.355	104025	864.6	19981
Run 25	45	100000.0	35	0.4	30000	10160	11067	160.8	73.59	82.47	1.121	2.624	13.88	1.913	73881	767.8	17273
Run 26	45	100000.0	35	0.4	45000	10050	11520	160.7	72.92	82.99	1.138	2.668	13.79	1.593	88673	763.2	18829
Run 27	45	100000.0	35	0.4	60000	9941	11983	160.6	72.19	83.55	1.157	2.718	13.7	1.235	114349	759.7	20941

Methods

- **GUI in Python**



Methods

- **GUI in Python**

SOLTERMIN

Summary | Weather Data | Solar Field | Receiver & Gas Cycle | MED-TVC | Simulation & Results

Task 4.3 - Solar Tower Gas Turbine Power Plant coupled with a MED-TVC plant

Solar Field: Heliostats & Tower

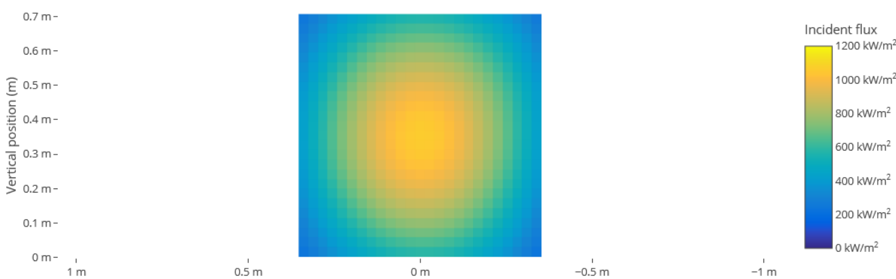
Diagram | Picture | Discretization | Discretization study

Atmosphere | Heliostats | Tower & Receiver | Layout

Grid

25 x 25

25x25, 20 March 22, 02 PM, **333.14 kW**



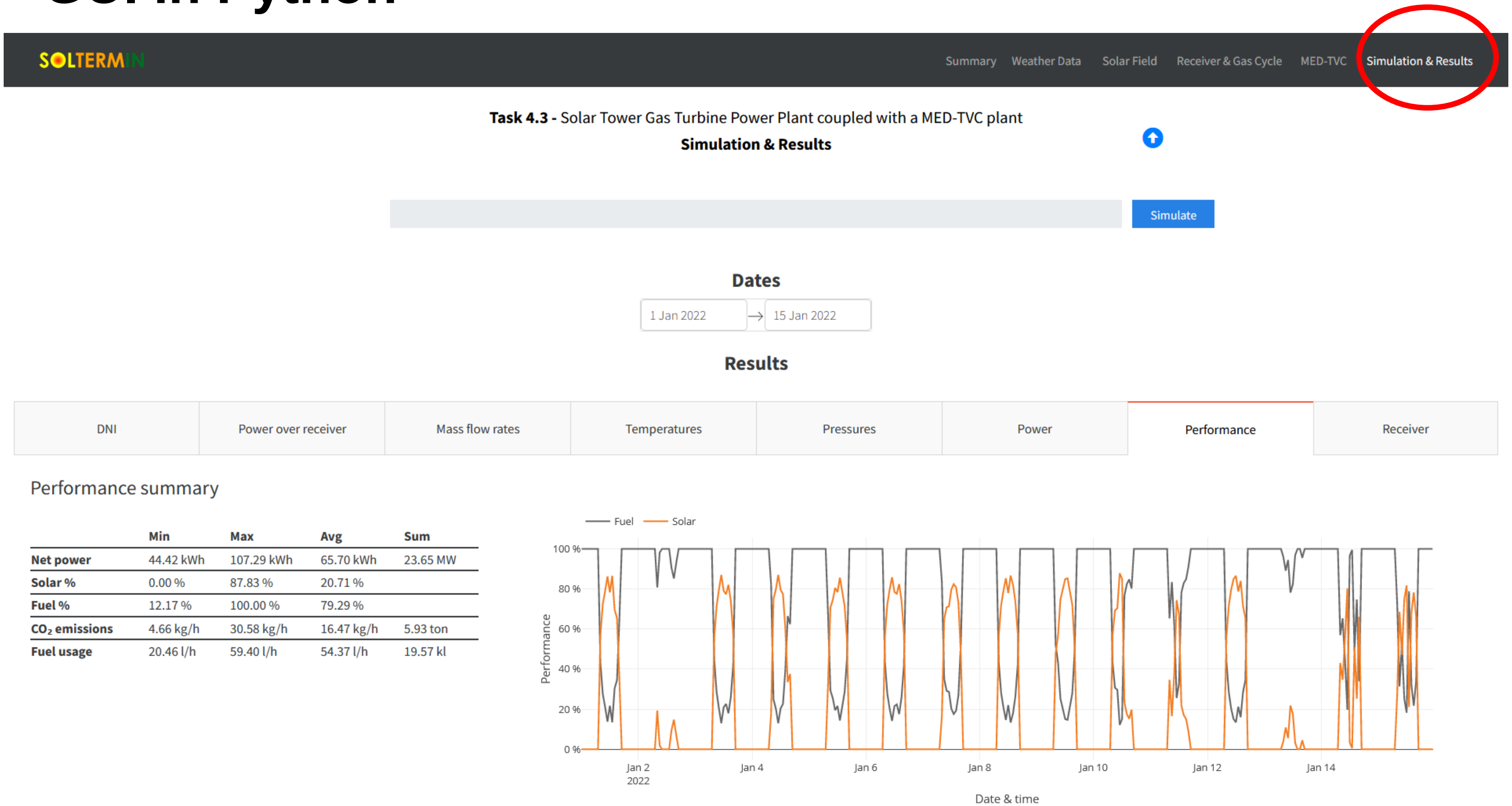
Parameter	Value	Units
Heliostat name	AORA Solar	-
Focusing type	At slant	-
Canting method	On-axis at slant	-
Number of heliostats	52	-
Heliostat height	4	m
Heliostat width	4	m
Heliostat reflectivity	0.94	%
Soiling factor	0.95	%
Number of heliostat facets - X	2	-
Number of heliostat facets - Y	2	-
Facets' gap - X	0.005	m
Facets' gap - Y	0.005	m
Ratio of reflective area to profile	1	%
Elevation pointing error	0	rad
Azimuth pointing error	0	rad
Surface slope error in X	0.00153	rad
Surface slope error in Y	0.00153	rad
Reflected beam error in X	0.00153	rad
Reflected beam error in Y	0.00153	rad
Optical error type (SolTrace only)	Gaussian	-

References

Solar Power tower Integrated Layout and Optimization Tool (SolarPILOT) - NREL
Demonstrating SolarPILOT's Python API Through Heliostat Optimal Aimpoint Strategy Use Case - NREL
SolarPILOT API (CoPILOT) - NREL
SolarPILOT User's Manual - NREL

Methods

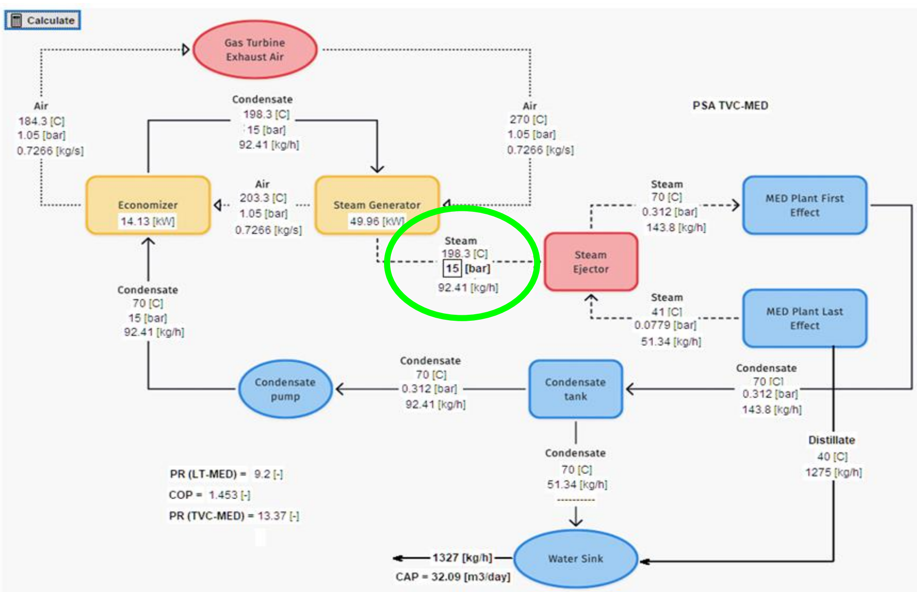
- **GUI in Python**

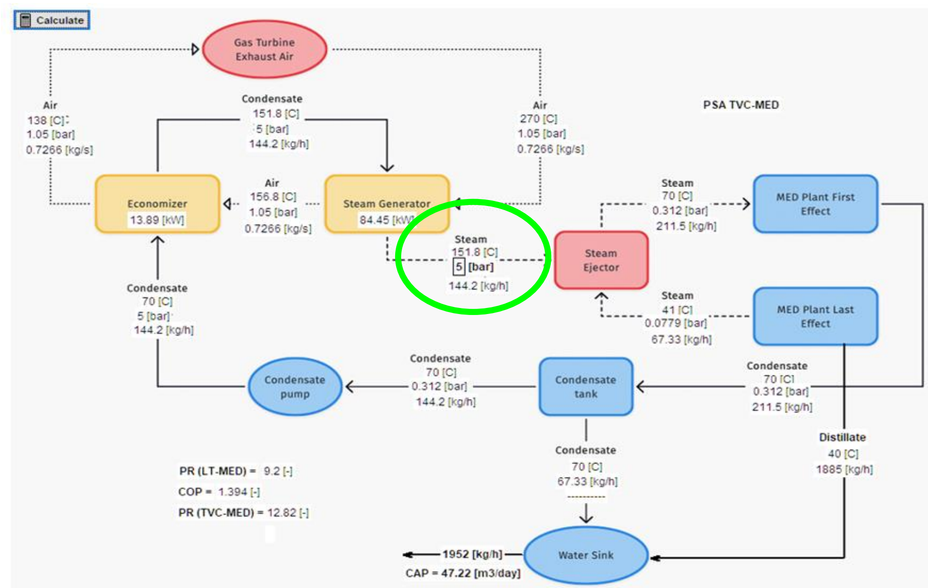


Contents

Results & discussion

- **Motive steam pressure analysis MED-TVC**
  - 15 bar, 198.3 °C ⇒ 32 m³/d, PR = 13.37
  - 5 bar, 151.8 °C ⇒ **47.2 m³/d**, PR = 12.8

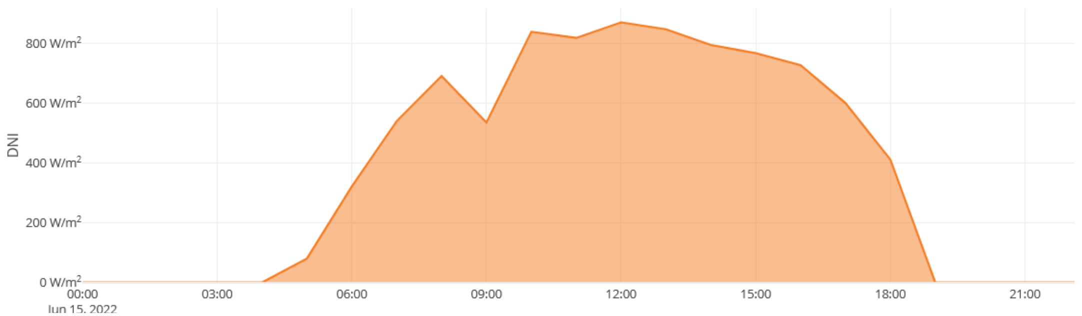


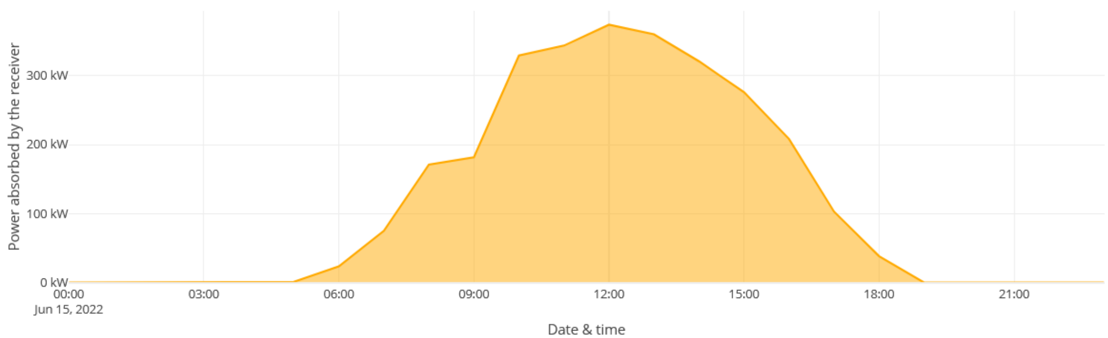


Results & discussion

- **Study case (only power)**
  - Location: PSA, Almería
  - Date: June 15

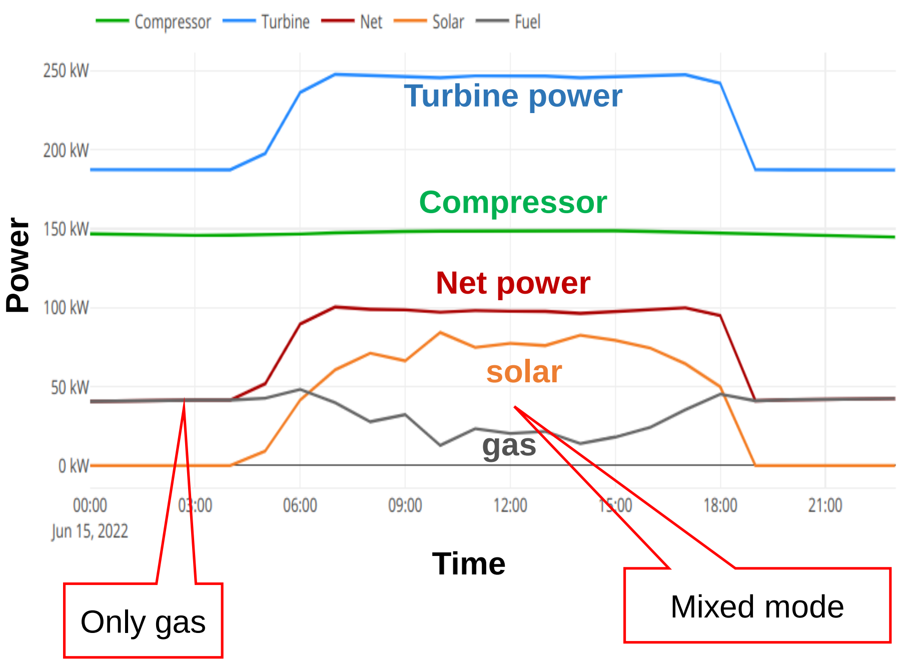
	Min	Max	Avg	Sum
DNI	0.00 W/m²	872.13 W/m²	369.10 W/m²	8.86 kW/m²
Power receiver	0.00 kW	389.11 kW	56.49 kW	20.34 kkW
Latitude	37.095000			
Longitude	-2.358549			
Start	15 Jun, 2022			
End	15 Jun, 2022			
Source	PVGIS			
Elevation	499.0 m			
Radiation DB	PVGIS-SARAH			
Meteo DB	ERA-Interim			
Horizon DB	DEM-calculated			

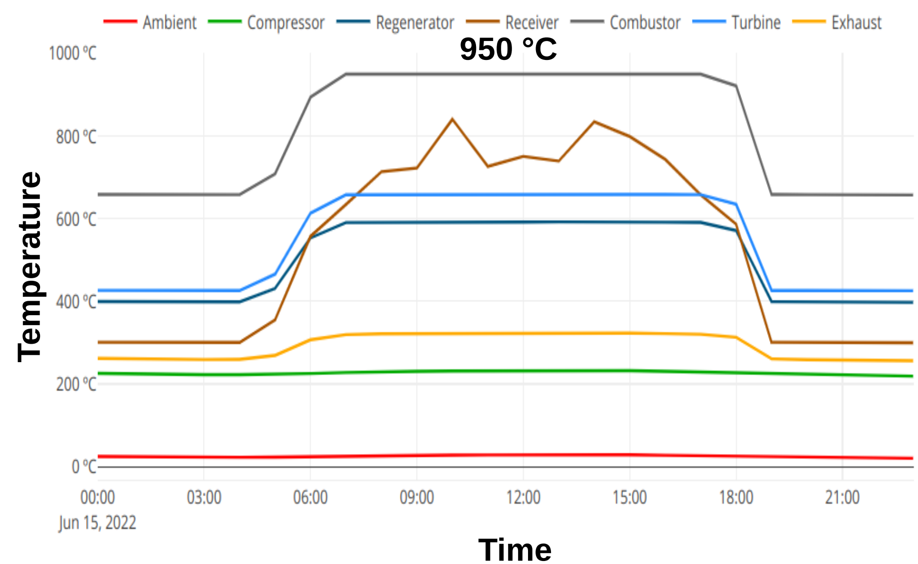




Results & discussion

- **Study case**





Contents

Conclusions

- A **simulation tool** able to estimate the annual power and water produced in a **hybrid solar mini-tower** with multi-effect distillation unit is being developed
- The results for a simulation period at any specific location includes **power distribution** over the receiver, temperature profiles, and ***performance*** indicators
- Two different ***motive steam pressures*** have been analyzed in the thermal vapor compressor in a preliminary analysis: 5 bar and 15 bar. The lowest motive steam pressure leads to the **higher water production** (47 m^3/d)

Acknowledgment

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Thank you very much for your attention

Questions?

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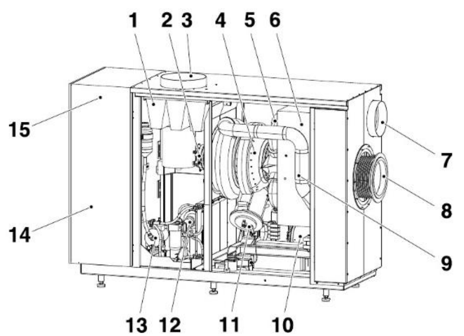
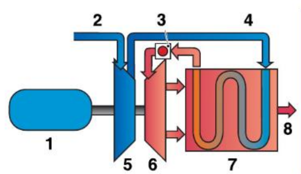
Appendix

Turbec T100 Natural Gas Microturbine System

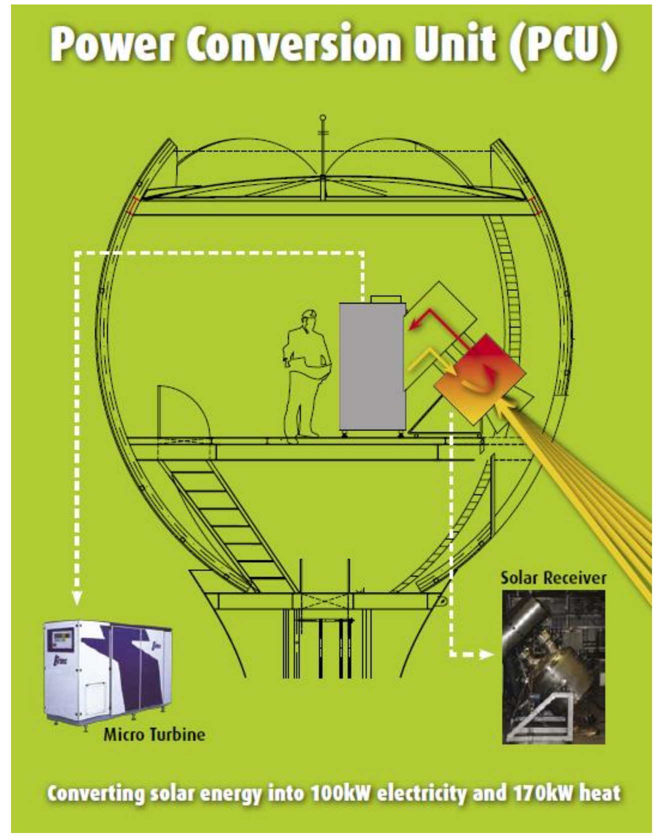
Technical description



1. Air filter
2. Generator
3. Air inlet
4. Gas turbine engine
5. Pipe from recuperator
6. Recuperator
7. Ventilation air outlet
8. Exhaust gas outlet
9. Pipe to recuperator
10. Gas compressor
11. Combustion chamber
12. Oil pump
13. Cooling water pump
14. Power electronics
15. Control system



1. Generator
2. Inlet air
3. Combustion chamber
4. Air to recuperator
5. Compressor
6. Turbine
7. Recuperator
8. Exhaust gases



Appendix

MED-TVC model