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Compressor Engineering
Refrigeration and Air Conditioning
High Performance Buildings

Experimental investigation of an ORC system for a micro-solar power plant

by

R. Dickes*, O. Dumont, S. Declaye, S. Quoilin, I. Bell and V. Lemort

Thermodynamics Laboratory
Aerospace and Mechanical engineering department
Faculty of Applied Sciences
University of Liège

sun2power

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Université de Liège

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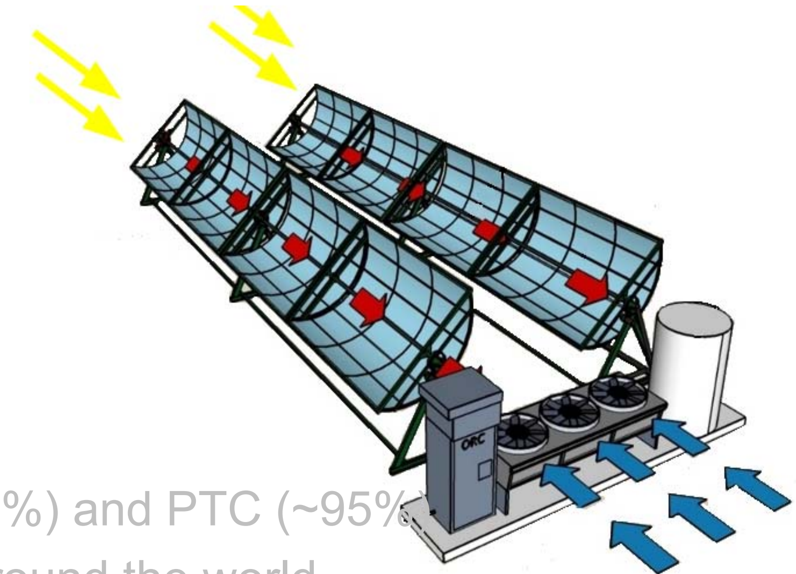
Introduction to CSP

CSP = Concentrated Solar Power

- Solar receivers
- Power unit
- Thermal energy storage



CSP nowadays :

- Solar tower (~3%) and PTC (~95%)
- < 2600 MWe around the world
- µ-CSP (<5kW) to large scale (400 MW)
- USA and Spain

Project "Sun2Power"

- 3kWe CSP facility
- Control investigation under dynamic operating conditions
- www.sun2power.eu

Introduction to CSP

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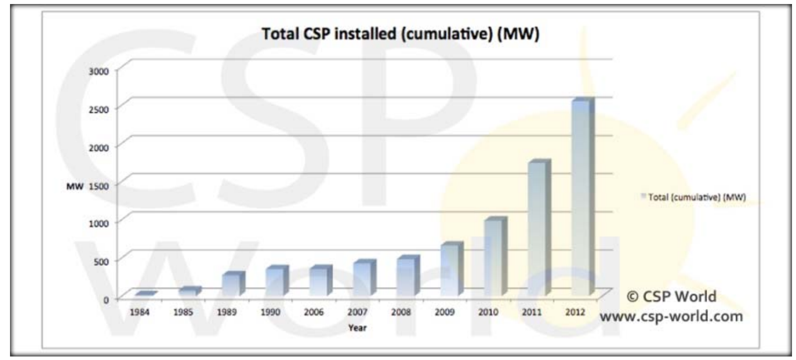

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Introduction to CSP

CSP = Concentrated Solar Power

- Solar receivers (S2P: Parabolic trough collectors)
- Power unit (S2P : Organic Rankine Cycle)
- Thermal energy storage (S2P : Thermocline tank)

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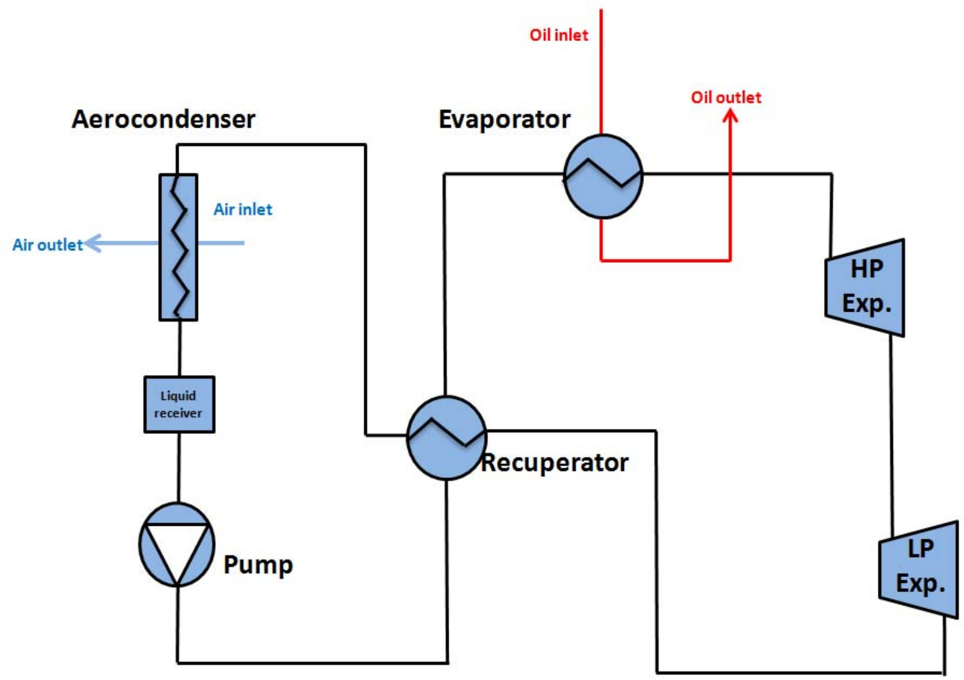
ORC test-rig description

Sun2Power test-rig:

- Recuperative ORC architecture
- Organic working fluid: HFC-245fa
- Components from the HVAC industry



ORC nominal operating conditions		
T_{ev}	140	°C
P_{ev}	28	bar
T_{cd}	35	°C
P_{cd}	2.1	bar
Q_{ev}	24	kW
Q_{cd}	20.5	kW
Q_{rec}	3.5	kW
W_{pp}	0.3	kW
W_{net}	2.8	kW
η_{ORC}	10.5	%

* Georges et al. , Design of a small-scale ORC engine used in a solar power plant, 2013

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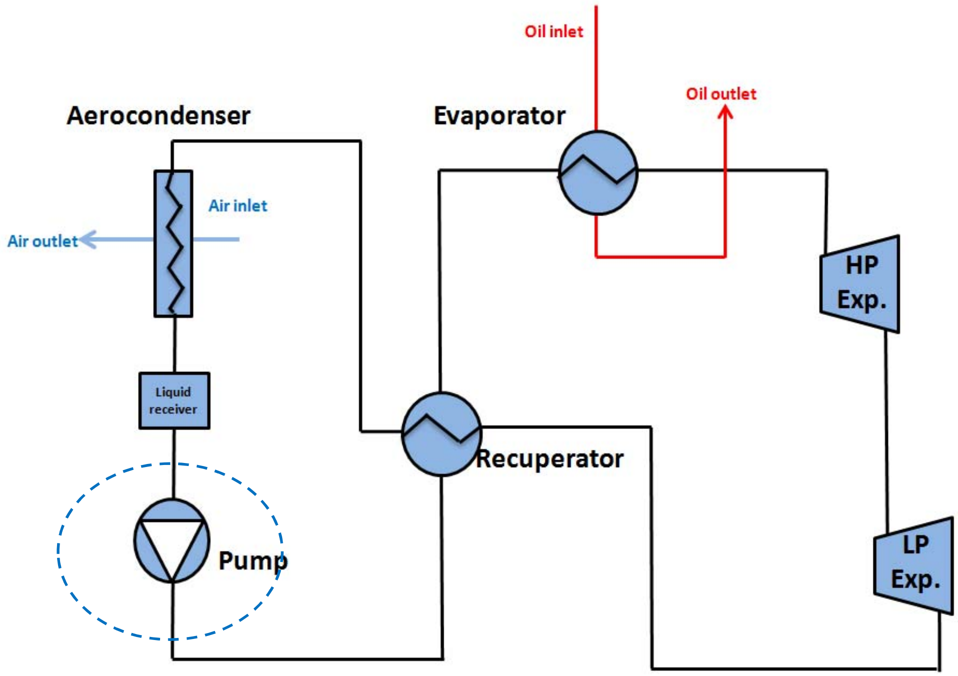


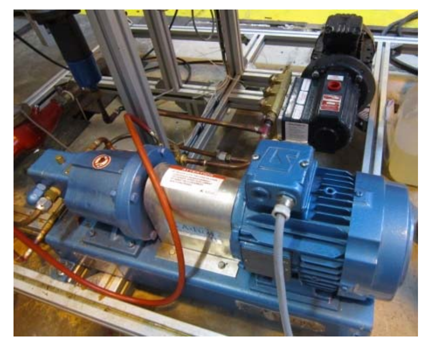
Pump

•Two pumps tested:

•Gear pump
(Viking SG-80550-M0V)

•Diaphragm pump
(Hydra-cell G13)

• N_{pp} regulated by a variable frequency drive



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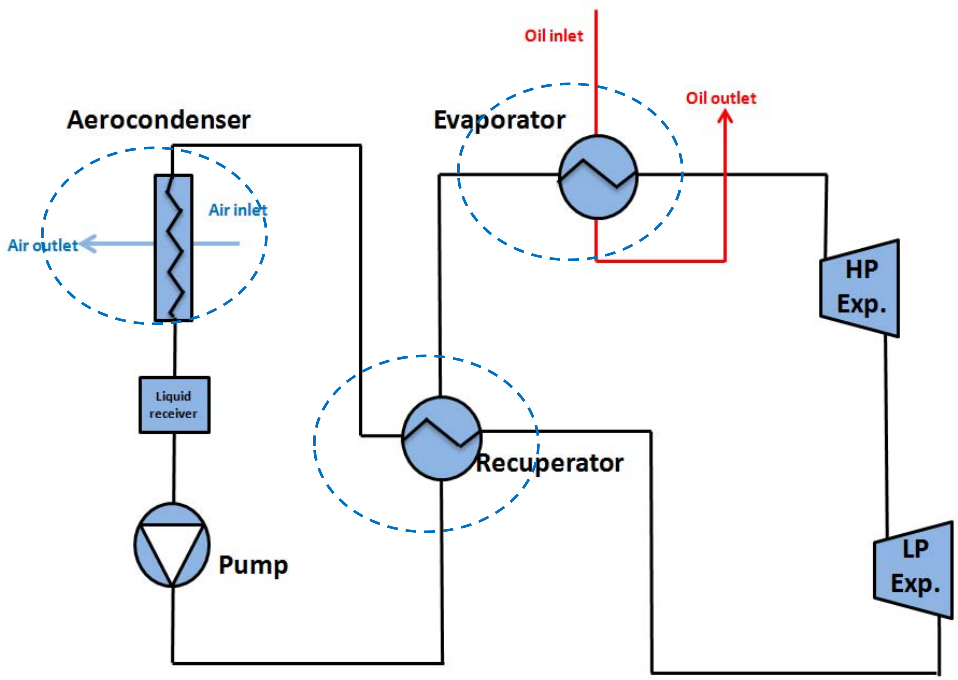

Heat exchangers

•Plate heat exchangers:
- Recuperator
(Alfa Laval CB30-40H-F)
- Evaporator
(Alfa Laval CB76-100E)

• Air-cooled fin coil exchanger
- •Condenser
(Alfa Laval Solar Junior 121)

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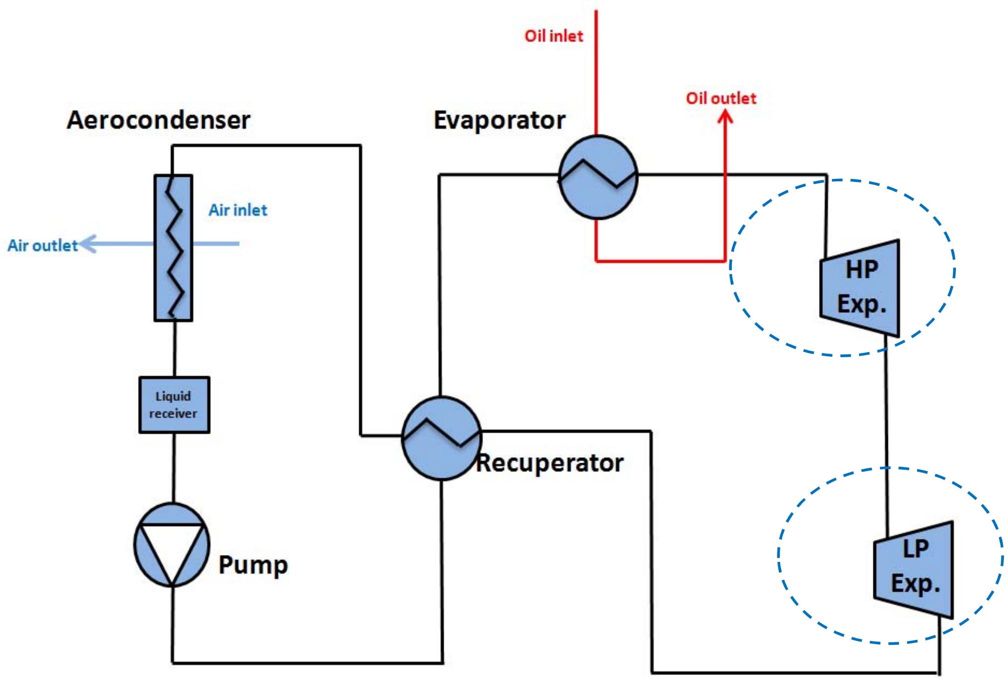

Expanders:

- Two scroll expanders in series
  - HP expander (Copeland ZR34K3E-ZD)
  - LP expander (Copeland ZR144KCE-TFD)
- Directly connected to the grid

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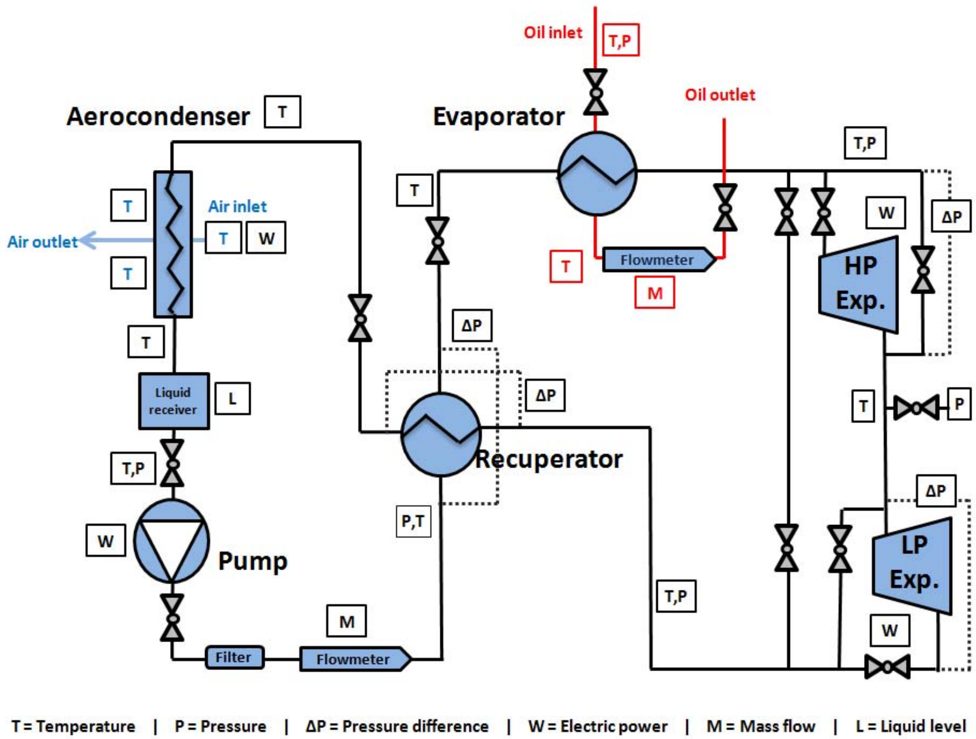
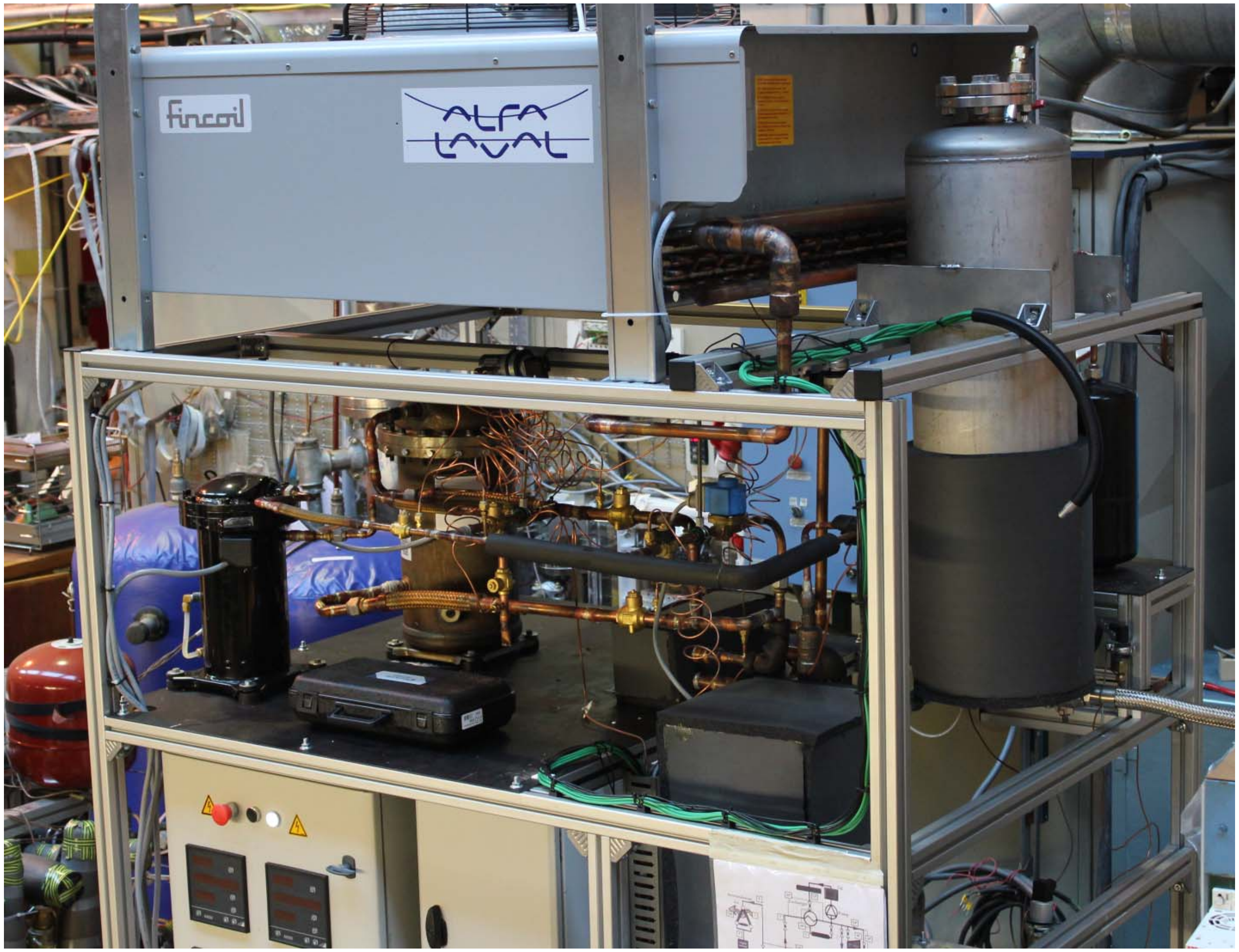


Measurements setup and acquisition:

- Absolute, gauge and differential pressure sensors
- T-types thermocouples
- Coriolis flowmeter and four wattmeters
- Acquisition and remote control via LabView

ORC test-rig description



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Experimental campaign and results

- 110 steady-state points

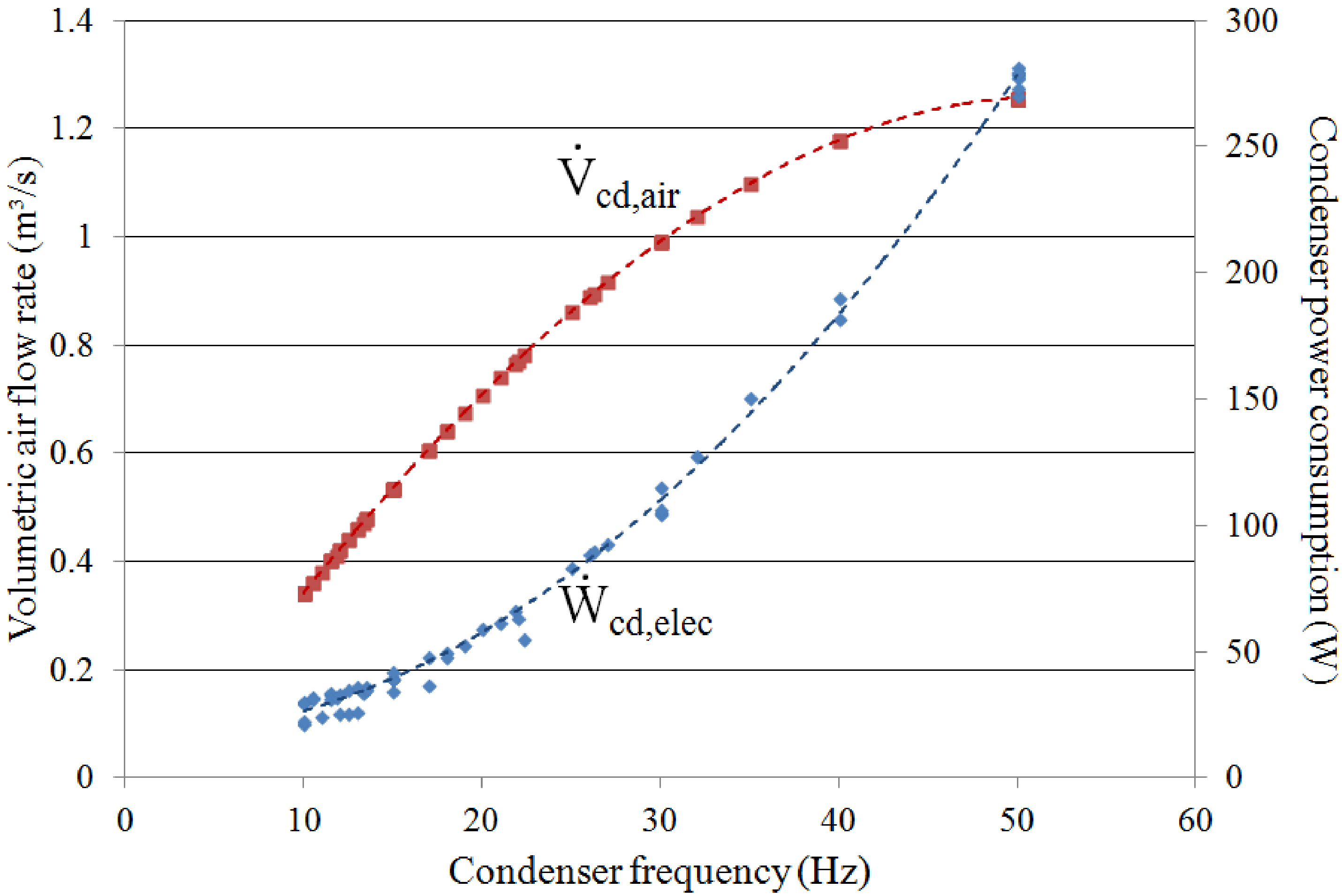
- 5 control variables:
  - o HTF flow rate;
  - o HTF supply temperature;
  - o Pump speed;
  - o Fan speed of the condenser;

- Single expander (HP) configuration

	Min	Max	
P_{ev}	14.5	22.6	bar
P_{cd}	2.1	7.9	bar
$T_{ev,ex}$	111	135	°C
$T_{cd,ex}$	25.8	61.8	°C
m_{R245fa}	76.2	149	g/s
$Q_{ev,th}$	14.6	29.5	kW
$Q_{cd,th}$	14.6	29.5	kW
W_{exp}	0.57	1.78	kW
W_{pp}	0.28	0.7	kW
W_{cd}	0.05	0.3	kW

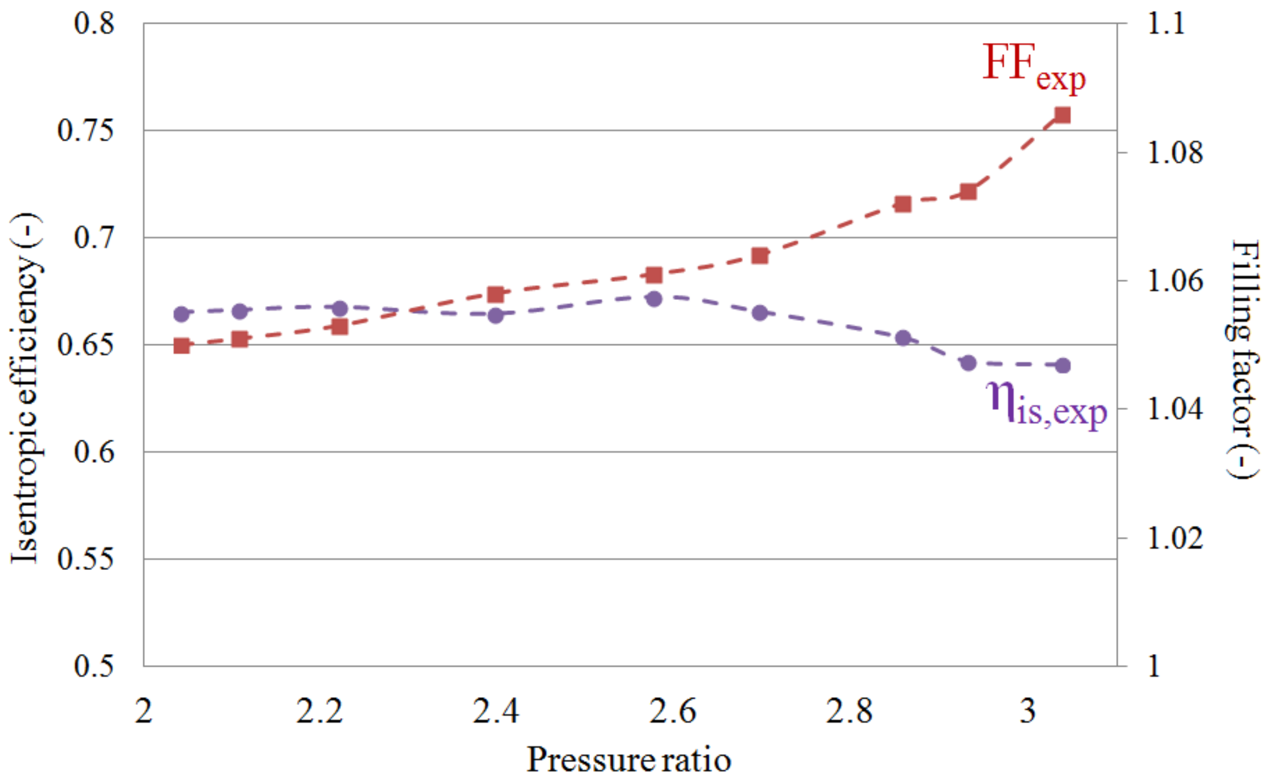
Experimental campaign and results

Air-cooled condenser performance (Alfa Laval Solar Junior 170)



Experimental campaign and results

HP expander performance* (Copeland ZR34K3E-ZD)



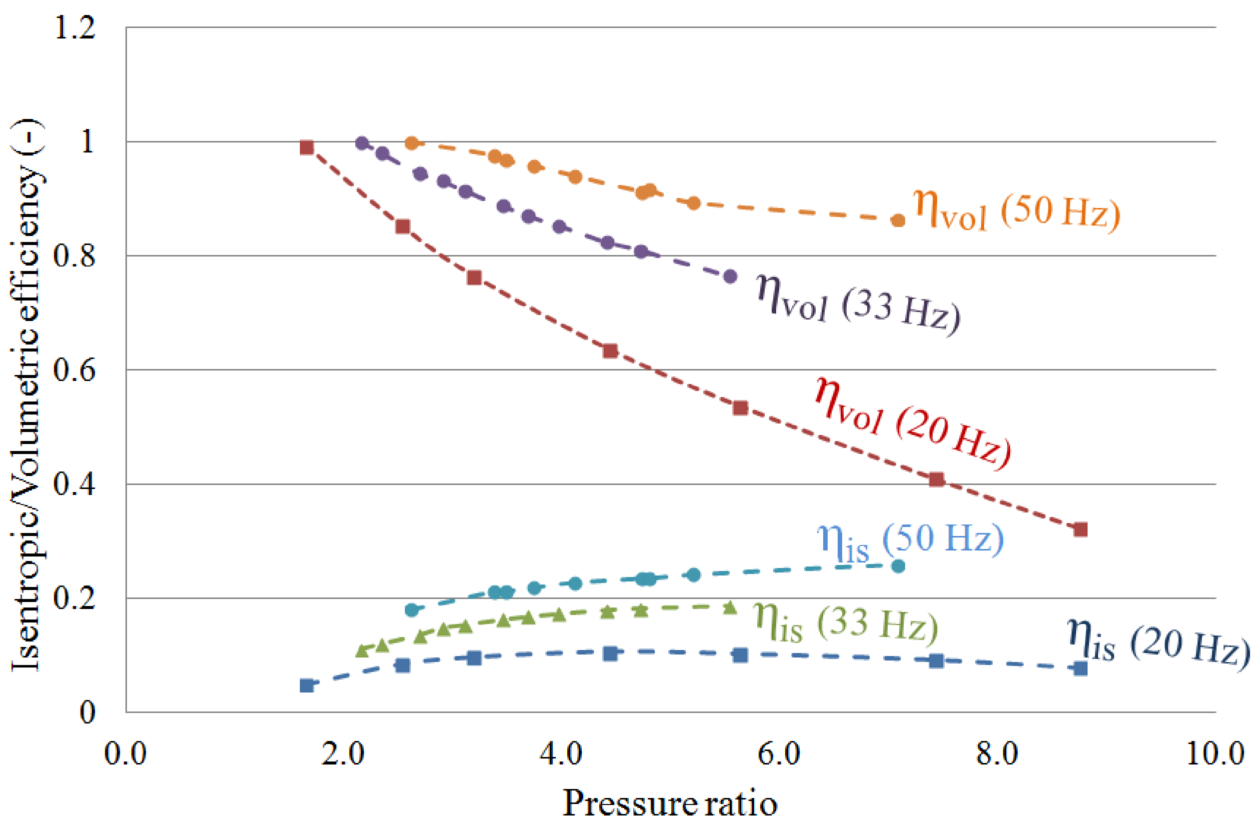
$$\eta_{is,exp} = \frac{\dot{W}_{elec,exp}}{\dot{m}\,(h_{su,exp} - h_{ex,exp,is})}$$

$$FF = \frac{\dot{V}_{meas,exp}}{\dot{V}_{th,exp}}$$

* Operating conditions ➔ Mass flow : 110 g/s and evaporating pressure: 18.6 bars

Experimental campaign and results

Gear pump performance (Viking SG-80550-M0V)



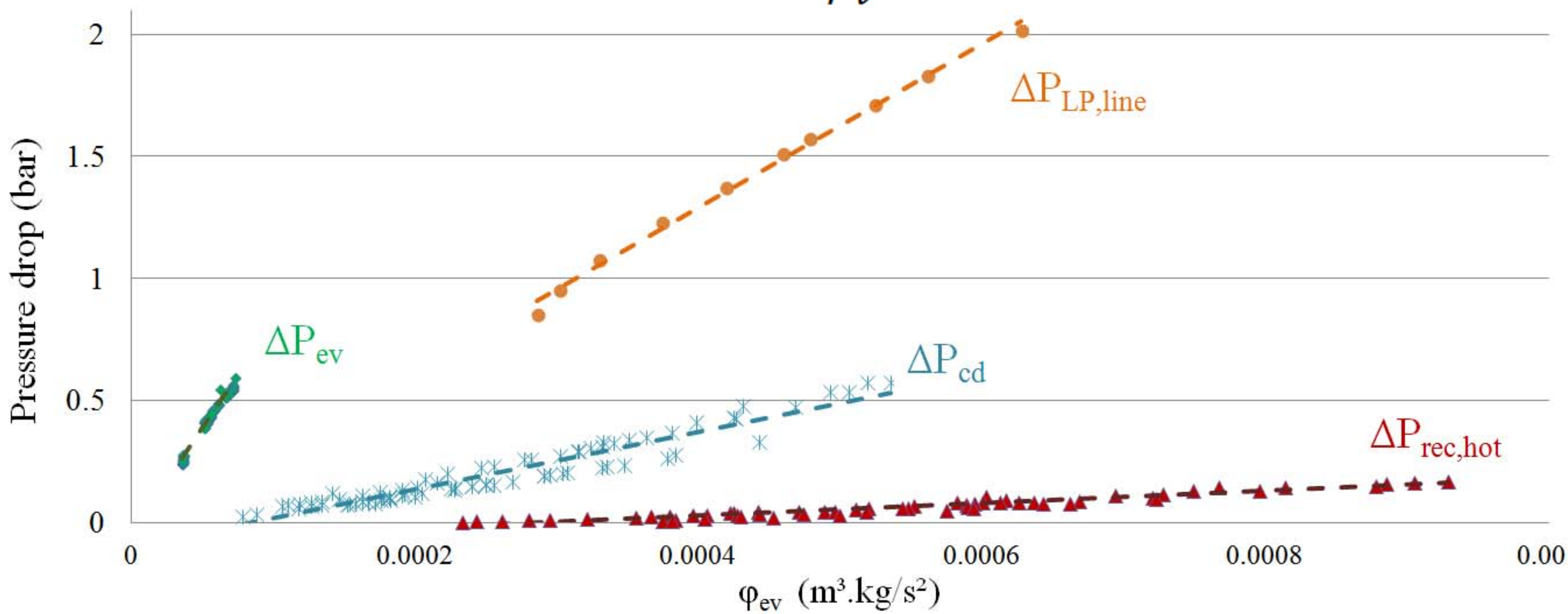
$$\eta_{is,pp} = \frac{\dot{m}\,(h_{ex,pp,is} - h_{su,pp})}{\dot{W}_{elec,pp}}$$

$$\eta_{vol,pp} = \frac{\dot{V}_{meas,pp}}{\dot{V}_{th,pp}}$$

Experimental campaign and results

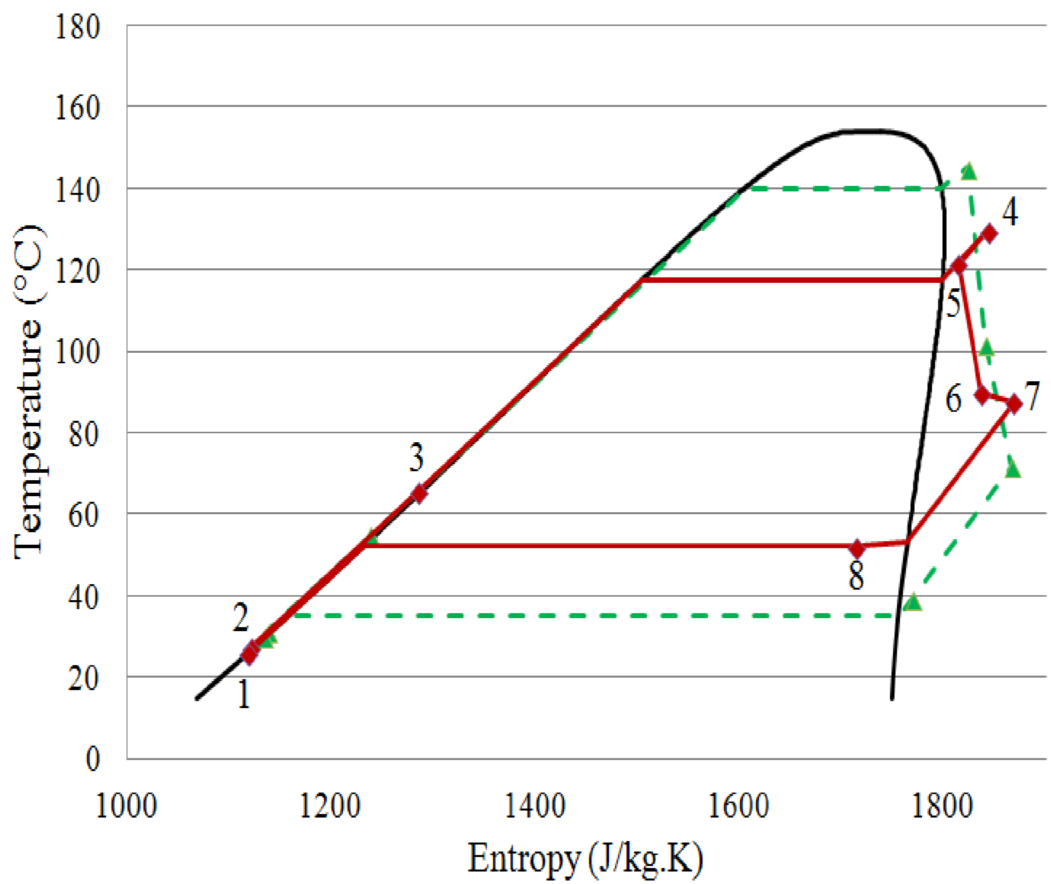
Pressure drops in the system

$$\Delta P = K.\phi + B \quad \text{with} \quad \phi = \frac{\dot{m}^2}{\rho_v}$$



Experimental campaign and results

Overall performance

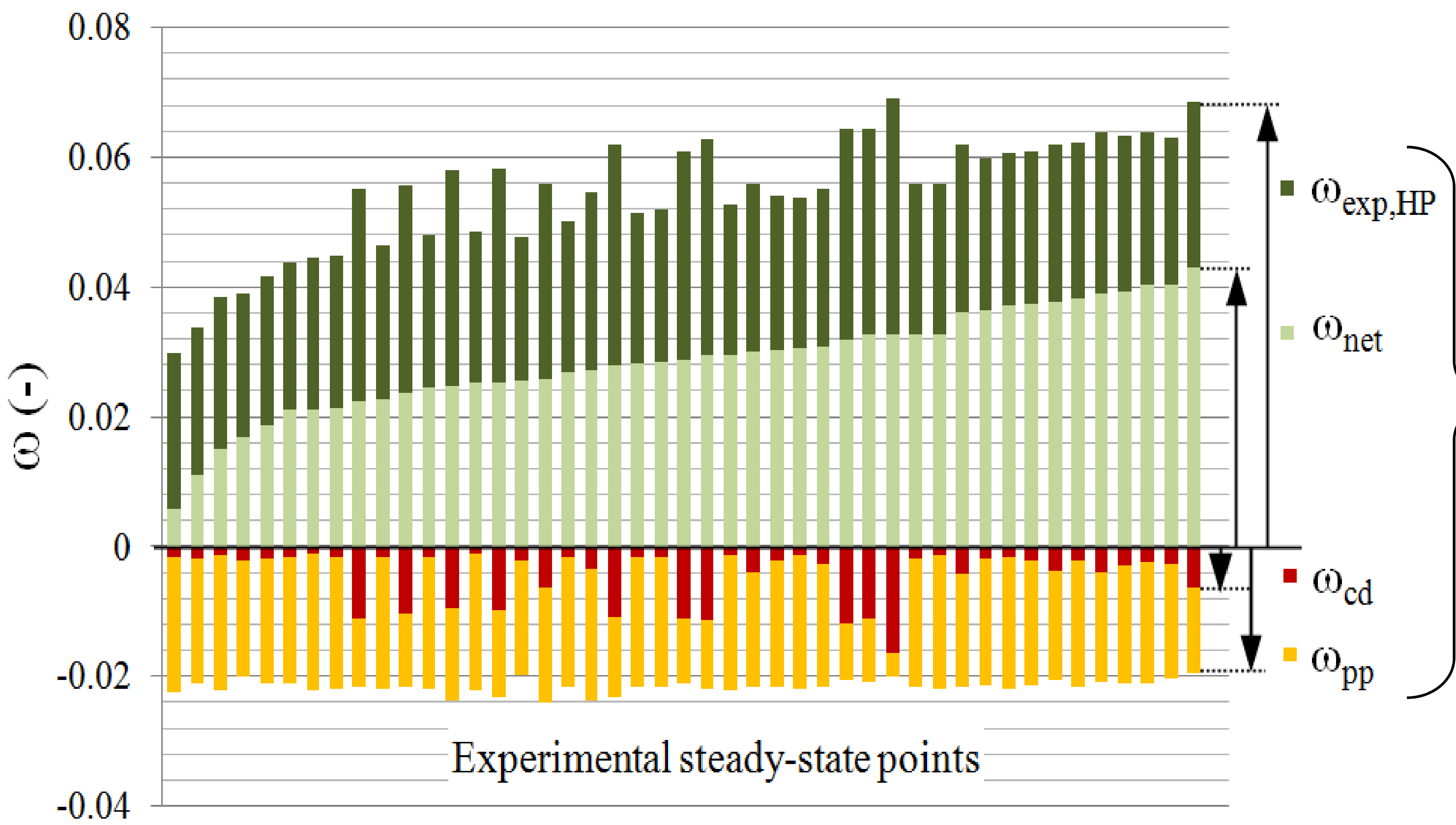


Best cycle performance		
Highest expander isentropic efficiency	68	%
Lowest expander filling factor	105	%
Highest cycle efficiency	4.5	%
Highest expander power generation	1780	W
Highest ORC net power generation	915	W

- Single expander configuration
- Excessive ΔP in LP line ➔ P_{cd} >>
- Expanders oversized ➔ P_{ev} <<
  - $r_{v,expected} > r_{v,actual}$
  - $V_{swept,expected} < V_{swept,actual}$
  - $P_{ev,expected} > P_{ev,actual}$

Experimental campaign and results

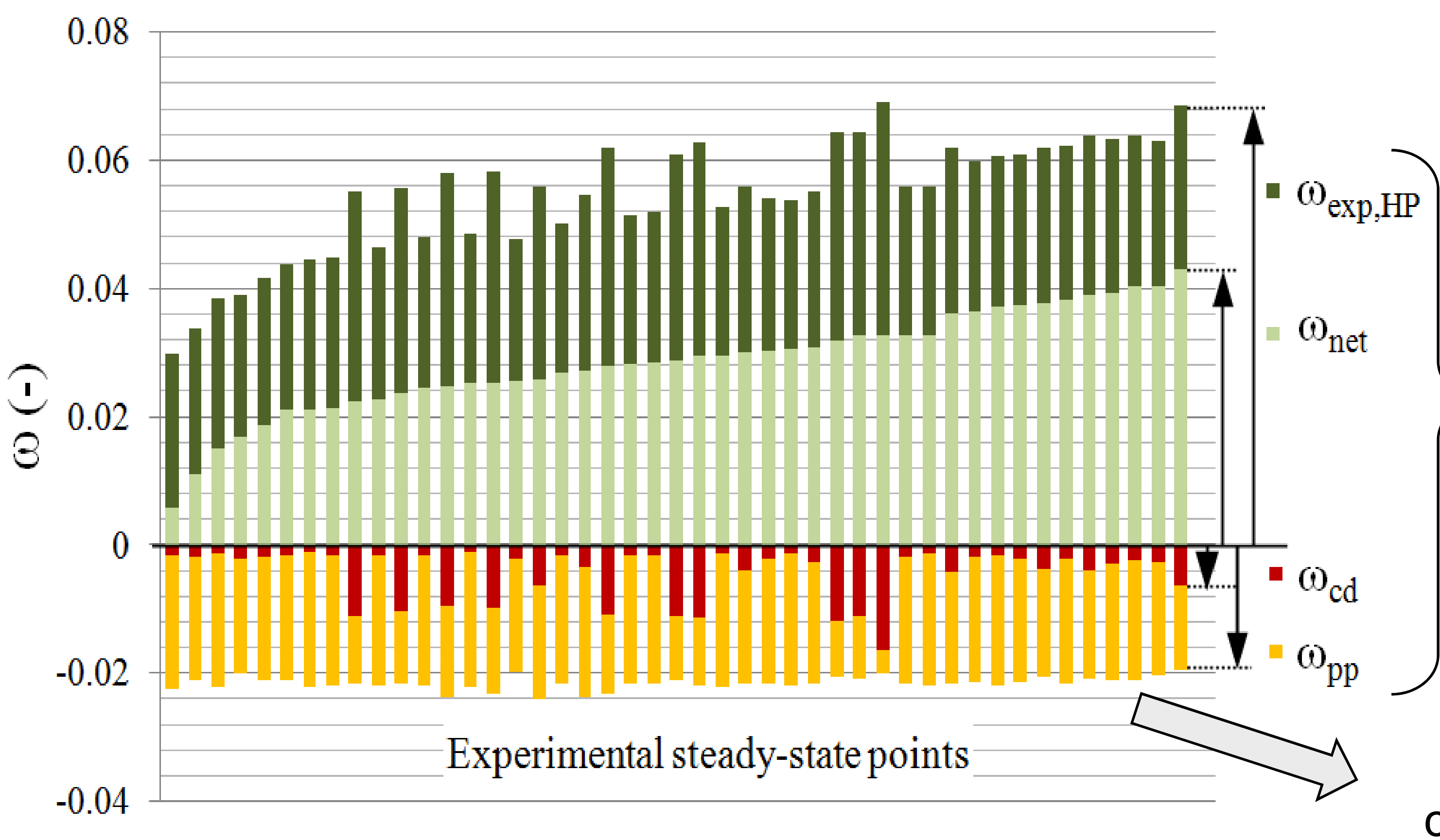
Overall performance – thermally normalized electrical powers



$$\dot{\omega} = \frac{\dot{W}_{elec}}{\dot{Q}_{ev}}$$

Experimental campaign and results

Overall performance – thermally normalized electrical powers



$$\dot{\omega} = \frac{\dot{W}_{elec}}{\dot{Q}_{ev}}$$

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Conclusion and perspectives

Perspectives:

- Improve the piping design in the LP line *(done);*
- Test the two (new) expanders operating in series;
- Calibrate a steady-state model of the test-bench from the experimental results;
- Derive an optimal control strategy mapping of the ORC in function of the heat source and heat sink conditions;
- Install the solar field + ORC + thermal heat storage system;
- Investigate dynamic control strategies of the whole system under transient operating conditions;

Conclusion and perspectives

Conclusion:

- Promising results for a first experimental campaign;
- Importance of some key parameters in the design process ($r_{v,exp}$, piping design, etc.)
- Opportunity for performance improvement: pump efficiency

Thanks for your attention

QUESTIONS?