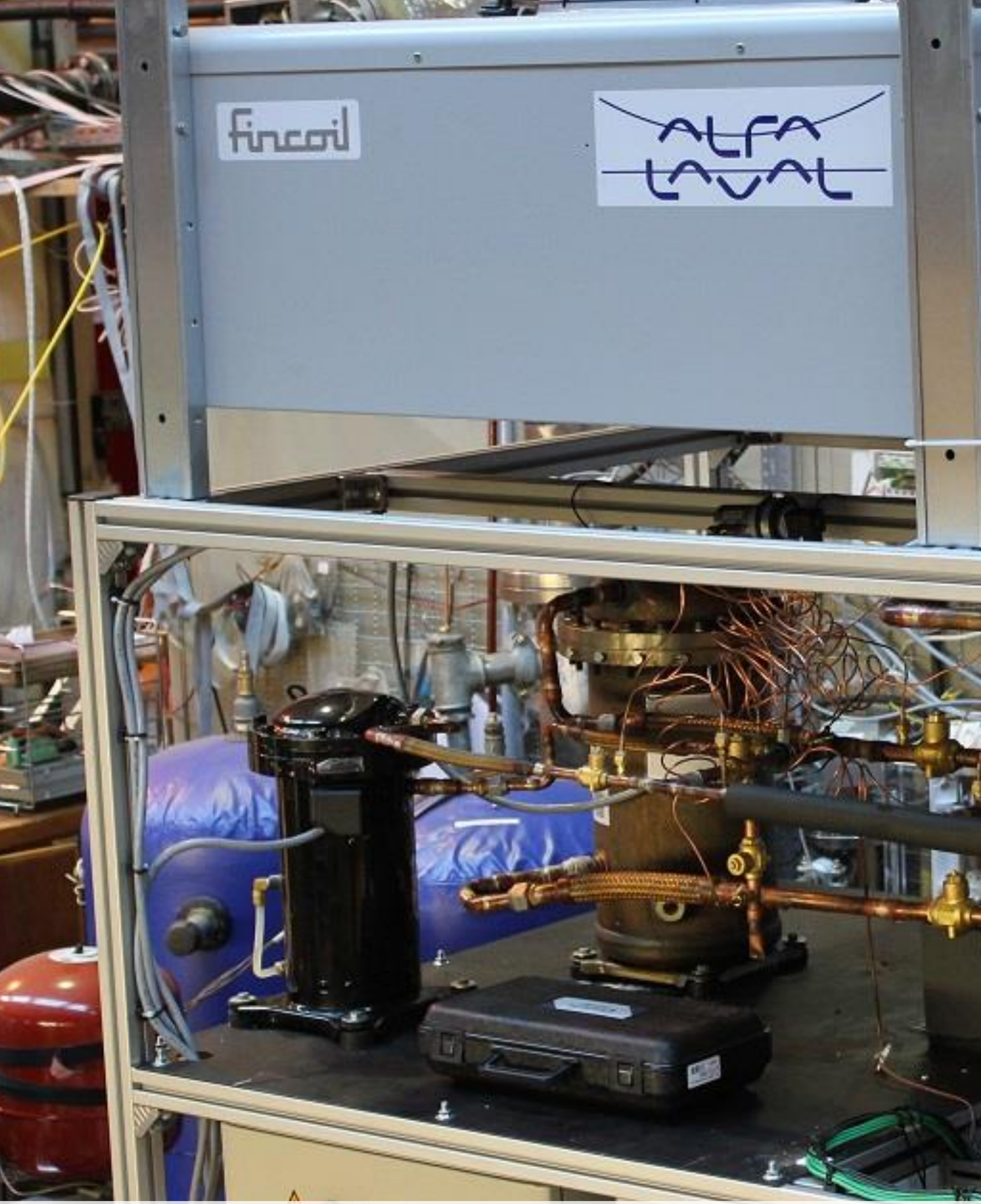

Performance correlations for characterizing the optimal off-design operation of an ORC power system

by

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LIÈGE université

THERMODYNAMICS LABORATORY
UNIVERSITY of LIÈGE

Presentation outline

1. Context
2. Case study
3. ORC off-design model
4. Performance optimization
5. Optimal performance mapping
6. Performance correlations
7. Conclusions and prospective work

1. Context

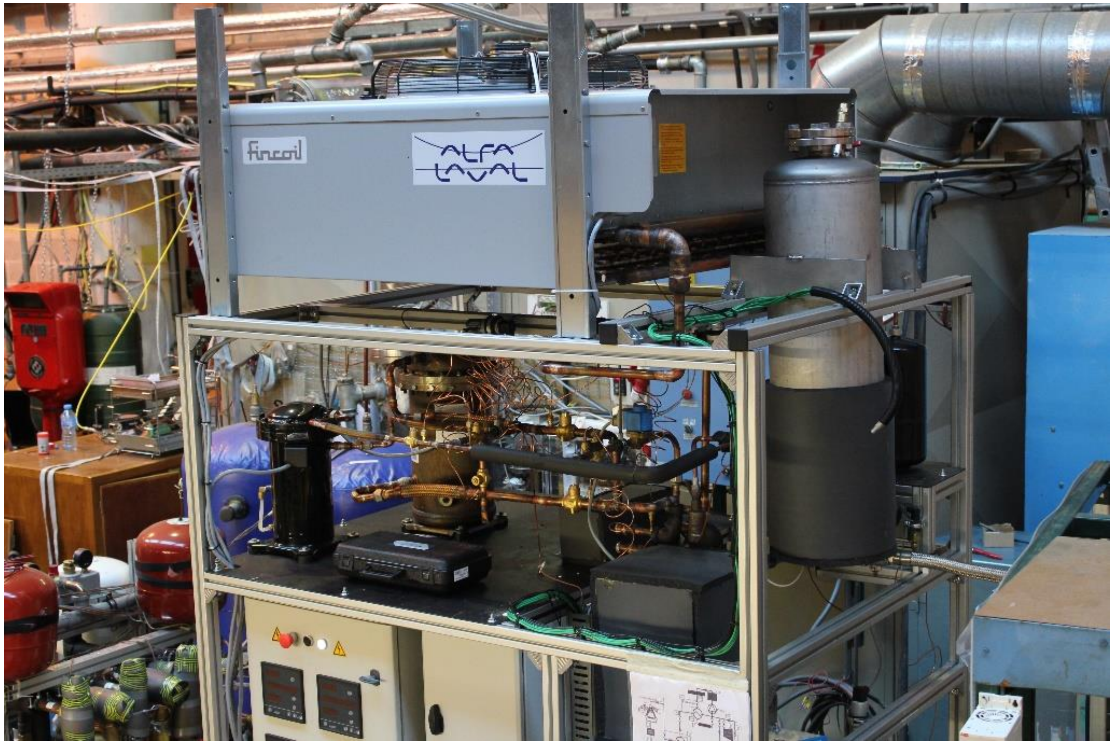
- ORC = Rankine cycle + Organic working fluid

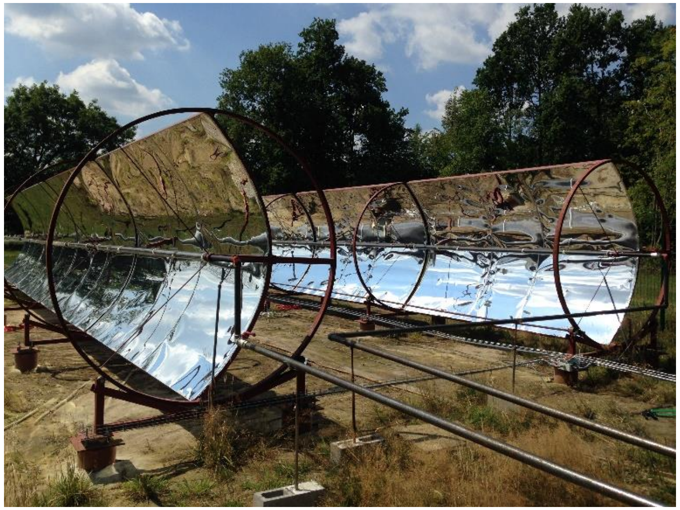
  - Thermal engine for low-grade heat source/ small-capacity application
  - Versatile operating conditions → ORC out of the nominal point
  - Change in the system performance and requirements of optimal control

GOAL:

- *Define optimal off-design performance mapping of ORC systems*
- *Derive simple analytical correlations for easy use in high-level simulations*

2. Case study

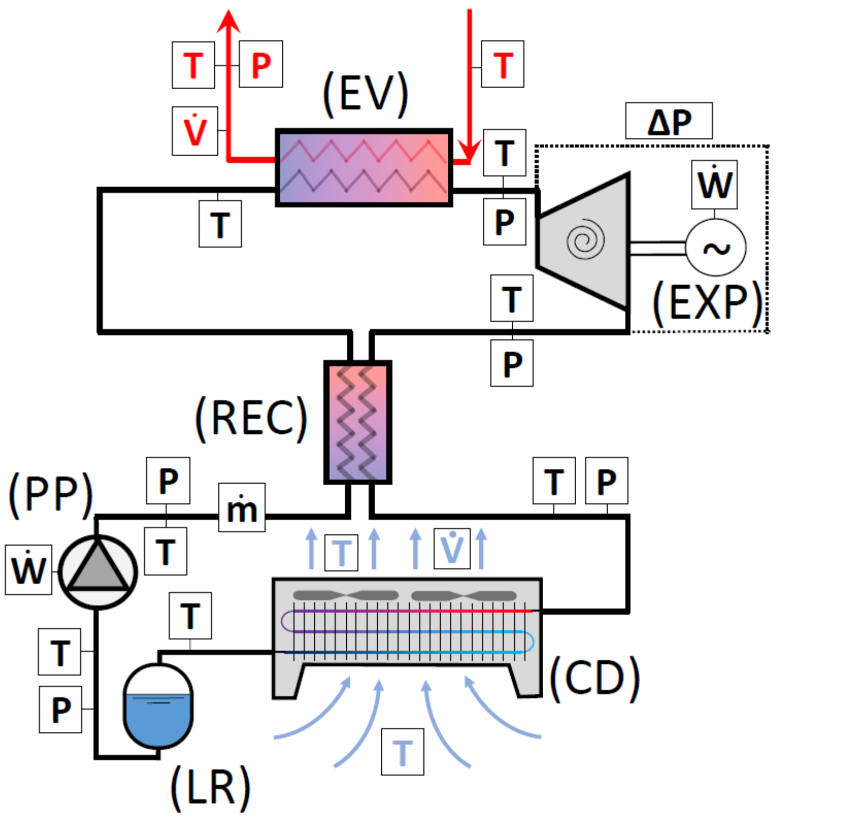




Sun2Power system at the University of Liège

- Solar field: 65m² of PTC
- HTF : thermal oil (100°C-150°C)
- 2kW ORC unit

2. Case study



P : pressure sensor - **T** : thermocouple - **ṁ** : mass flow meter
Ẇ: power meter - **V̇** : volumetric flow meter

Sun2Power ORC unit:

- 2kWe recuperative ORC
- R245fa as working fluid
- Scroll expander + diaphragm pump
- <u>Two BPHEXs (EV + REC)</u>
- <u>One fin coil air-cooled condenser</u>

→2 control variables:

- Speed of the pump
- Speed of the air-cooler fan

Reference database:

- Experimental measurements
- Post treatment (outliers + reconciliation)
- Complete range of conditions (40 pts)

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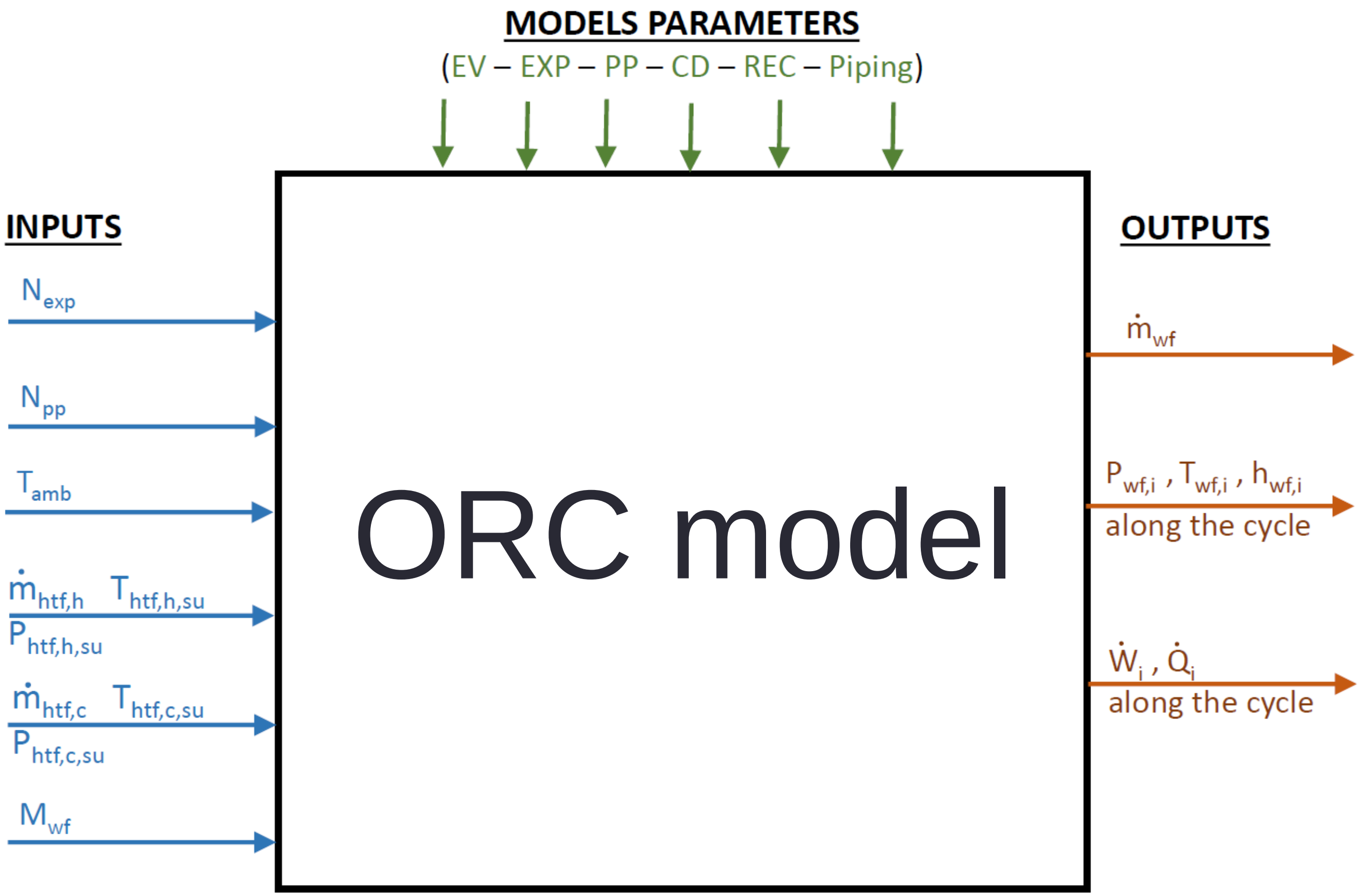
3. ORC off-design model



Charge-sensitive ORC model → No assumption in the system state (e.g. an imposed subcooling)

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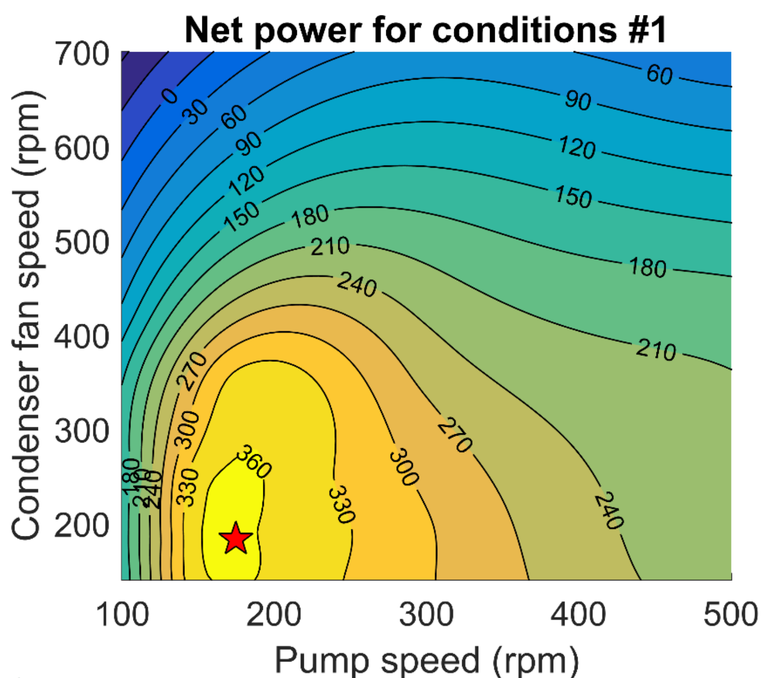
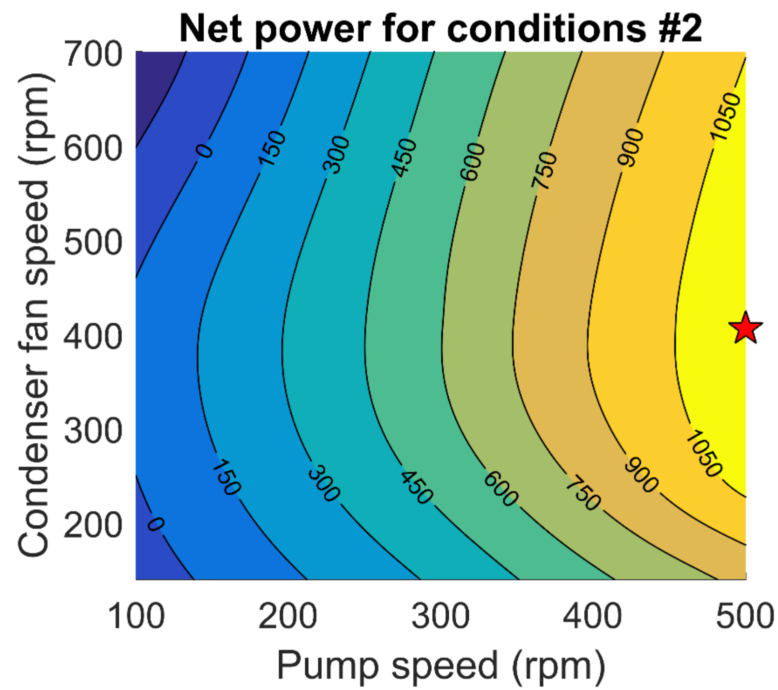
4. Performance optimization

- Off-design model → build performance mapping for any external conditions
- Seek optimal pump/air-cooler speeds to maximize ORC performance ($\dot{W}_{net}$)



$\dot{m}_{htf} = 50g/s$
$T_{amb} = 15°C$
$T_{htf,su} = 120°C$

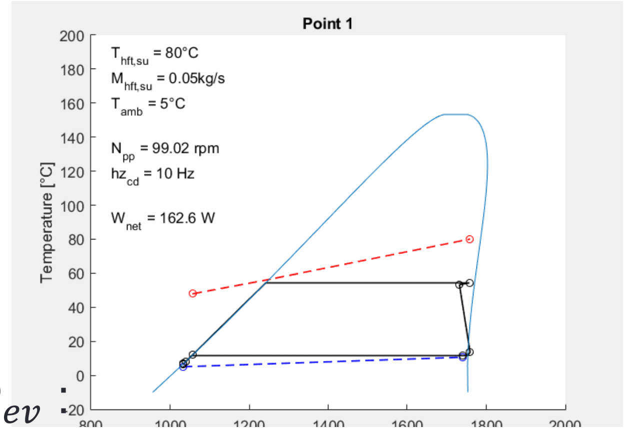


$\dot{m}_{htf} = 2kg/s$
$T_{amb} = 35°C$
$T_{htf,su} = 180°C$

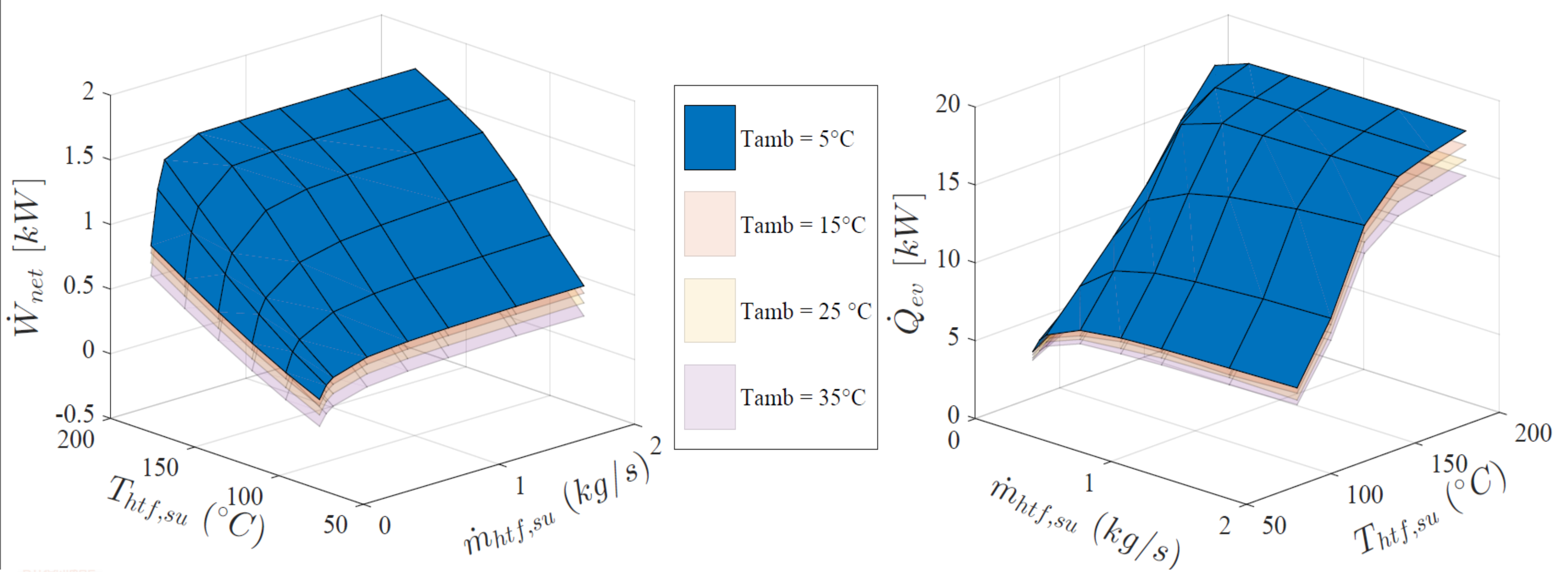
5. Optimal performance mapping

- Performance optimization over entire range of conditions:
  - HTF supply temperature: 80 → 180°C
  - HTF supply fow rate: 0.05 → 2 kg/s
  - Ambient temperature: 5 → 35 °C

  } 192 ≠ pts



- Optimal performance mapping in terms of $\dot{W}_{net}$ and $\dot{Q}_{ev}$:



6. Performance correlations (example for $\dot{W}_{net}$)

If considering the normalized variables :

$$\Omega = \frac{\dot{W}_{net}}{\dot{W}_{nom}} \qquad \Theta = \frac{T_{htf,su}(K)}{T_{htf,su,nom}(K)} \qquad \phi = \frac{\dot{m}_{htf,su}}{\dot{m}_{htf,su,nom}}$$

The net power (Ω) generated in any conditions can be computed as

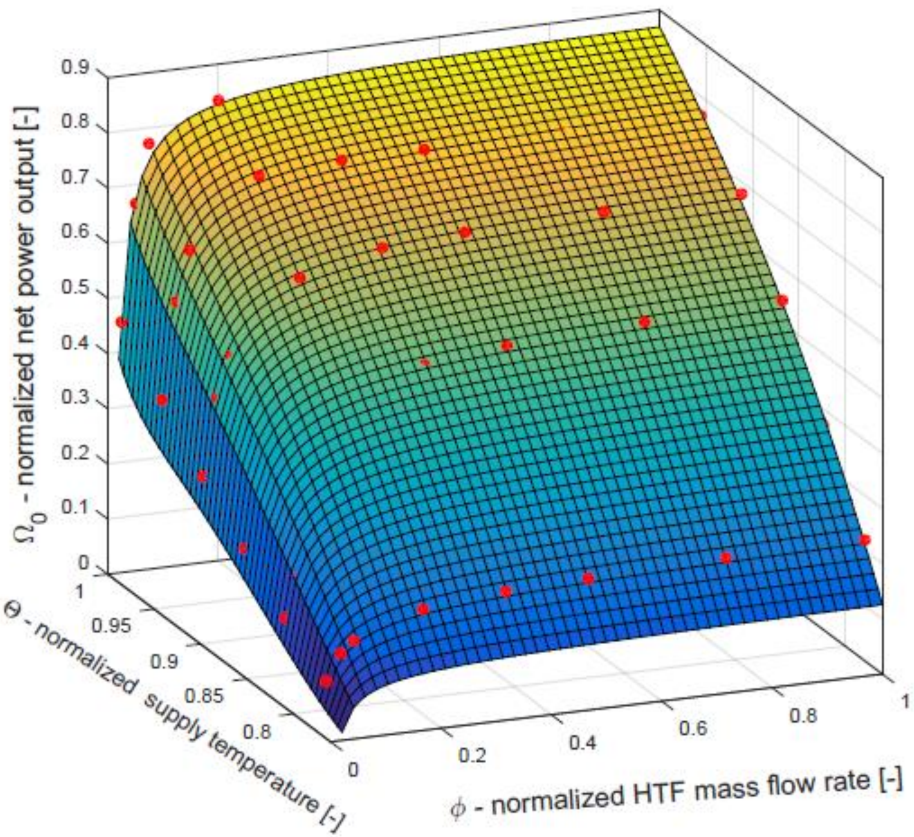
$$\Omega = \Omega_0 + \Delta\Omega$$

Ω_0 : net power generated in function of the HTF supply conditions (Θ, ϕ) <u>at a reference ambient temperature</u>

$\Delta\Omega$: correction factor accounting for the effective ambient temperature (if $T_{amb} \neq T_{amb,0}$)

6. Performance correlations (example for $\dot{W}_{net}$)

Correlation for Ω_0



Effect of HTF mass flow rate ϕ :

$$\Omega_0 = K_1 \left(1 + \frac{K_2}{\phi^{K_3}}\right)$$

Effect of HTF supply temperature Θ :

$$K_i = a_i \cdot \Theta^{b_i} + c_i$$

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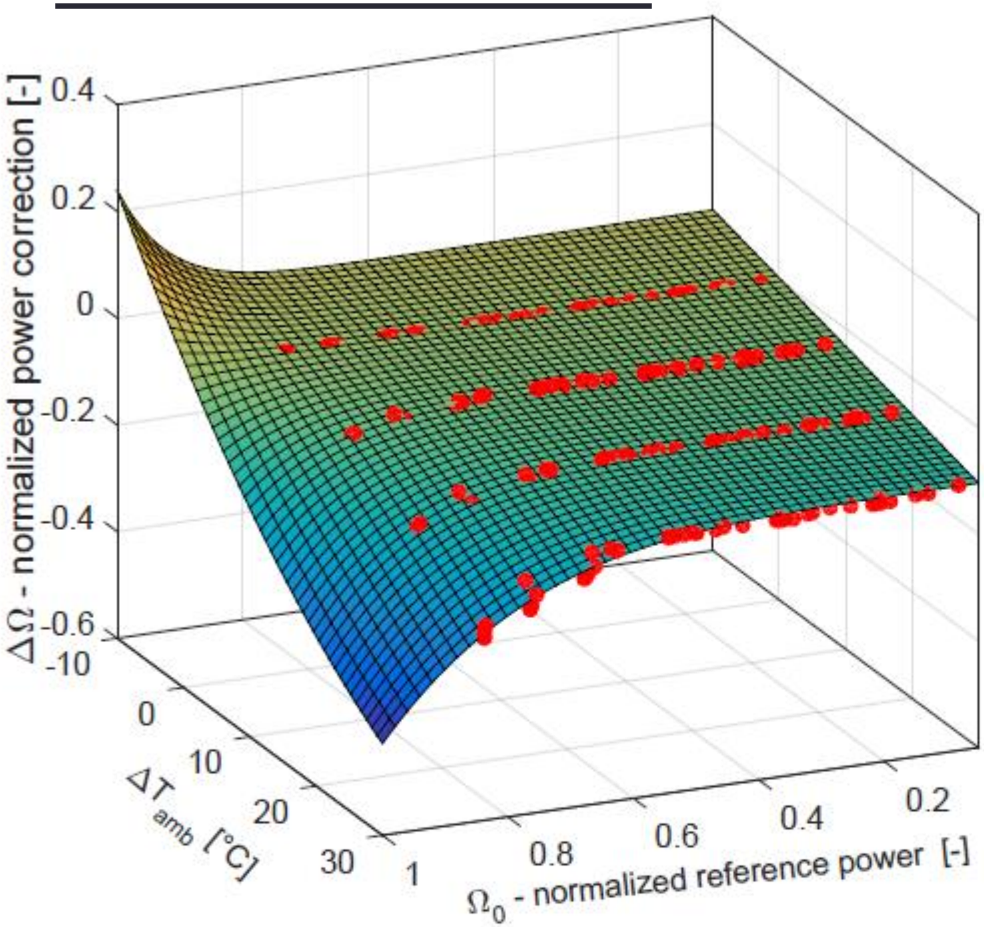
6. Performance correlations (example for $\dot{W}_{net}$)

Correlation for ΔΩ



Effect of the ORC load Ω_0 :

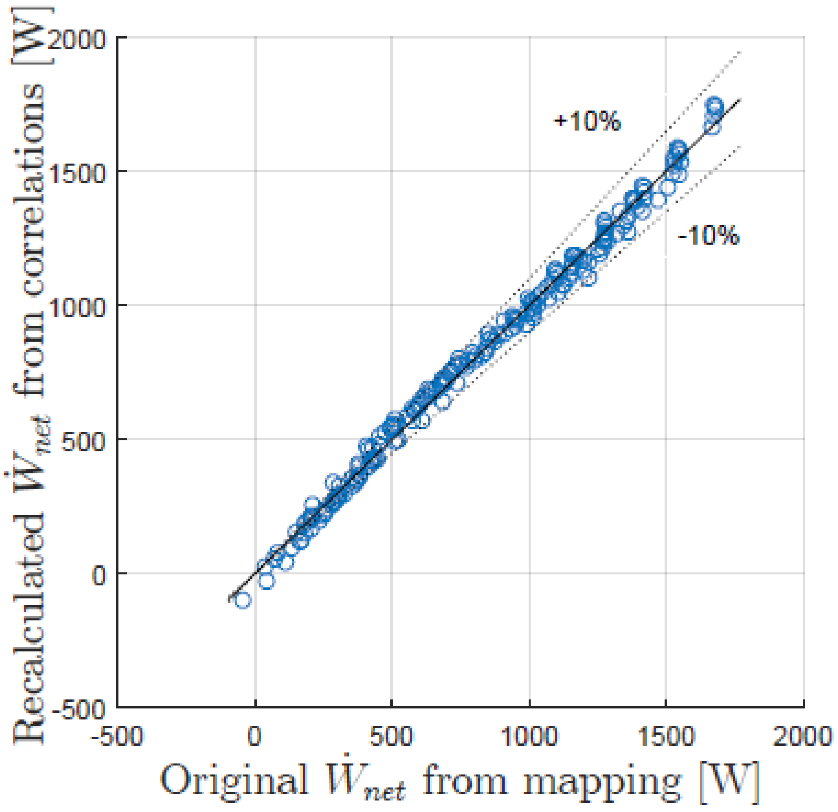
$$\Delta\Omega = L_1\left(1 + \frac{L_2}{\Omega_0^{L_3}}\right)$$

Effect of the ambient temperature :

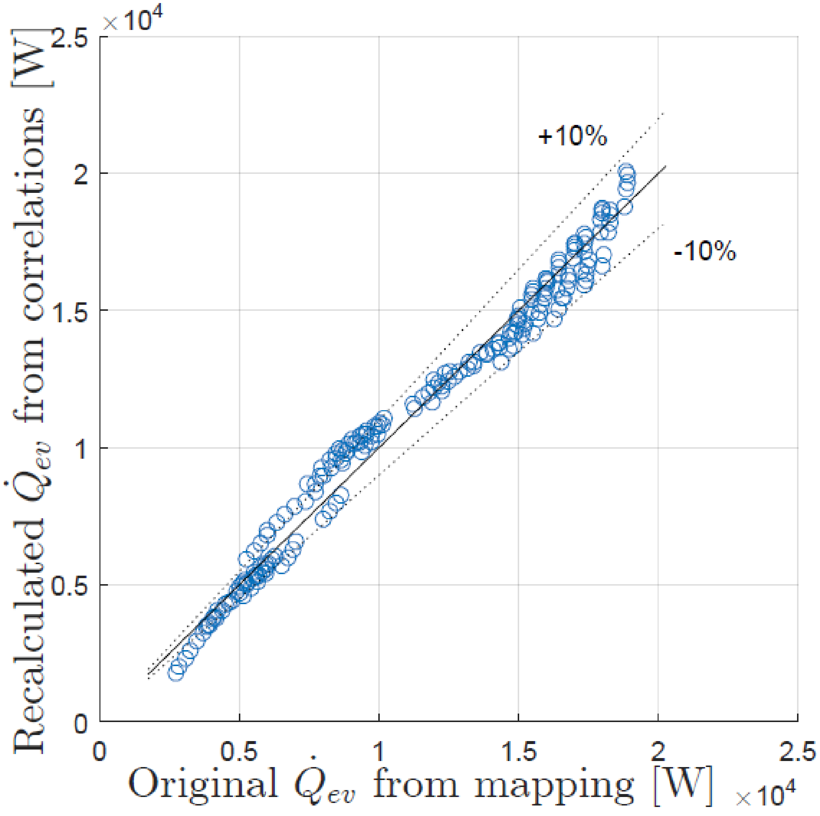
$$L_j = a_j \cdot \Delta T_{amb}^{b_j} + c_j$$

6. Performance correlations

$\dot{W}_{net}$



$\dot{Q}_{ev}$



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7. Conclusions and prospective work

Conclusions:

- 2kWe ORC unit used as case study
- Charge-sensitive ORC model used to predict off-design behaviour
- Optimal performance mapping derived over entire range of conditions
- Definition of analytical correlations to permit simple use in high-level simulations

Future work?

- Also characterize the optimal part-load performance
- Define the same performance correlations with another system

Additional information?

- Manuscript of the presentation available in the conference proceedings

- ORCmKit : open-source modelling library for ORC in Matlab, Python, EES (available at https://github.com/orcmkit)

- *«Charge-sensitive modelling of organic Rankine cycle power systems for off-design performance simulation»* → entire and detailed study to be published soon in Applied Energy (expected in November 2017)

Thanks for your attention

Any questions?

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