

Power-to-Heat and Heat-to-Power Prototype (500 kWth / 50 kWe)

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WeForming

• WeForming aims to transform buildings from passive consumers into strategic players in forming the energy networks of the future. The project focuses on Intelligent Grid-Forming Buildings (iGFBs), structures designed to actively contribute to an interoperable greener energy ecosystem, encompassing networks and markets.

https://weforming.eu/



Luxembourg multi-energy grid-interactive district with a large fleet of electric vehicles PORTUGAL shopping mall with internal power generation and energy storage systems CROATIA grid-supporting renewable districts on a holiday island with seasonal demand variation BELGIUM interactive residential district with bidirectional power-to-heat and thermal storage capabilities SPAIN grid-supporting rural renewable energy community

Validation through different demonstrators





WeForming

Intelligent green District



Interactive district with bidirectional power-to-heat

- EV charger
- PV and PT
- CB
- EV
- DHN

Energy market-driven multisector smart district



- EV charger
- PV
- CHP
- BESS
- HP



- BESS
- Biomass boiler
- Fuel cell





- CHP gas plant
- EV charger
- Ice storage
- Gas boiler
- Chillers



Grid-supporting districts with large seasonal demand variation



- EV charger
- **LED**



- PV
- HVAC
- EV charger
- BESS



CB?

Energy context: Paris Agreement (limiting warming to 1.5 °C), carbon neutrality by 2050, the role of renewable energies...nevertheless, problems related to their fluctuations and randomness.

- Energy storage is a key factor for fully migrate towards renewable energies.
- Among the storage techniques, Carnot Battery has the advantage of supplying electricity, heat and/or cold.
- The technologies also have the advantage of directly **integrating low-temperature** sources to create and connect **multi-energy systems**.

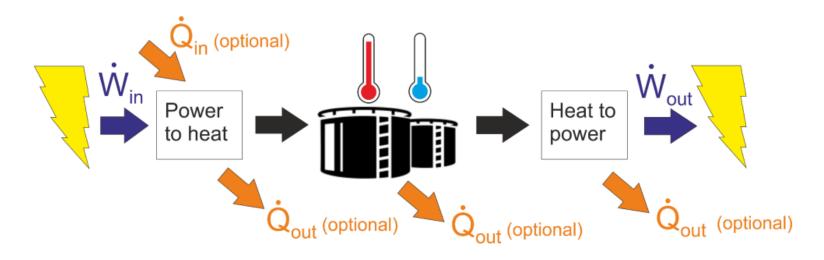


Figure 1. Mainly Concept of the Carnot Battery (Novotny, et al. (2022))



Agenda









SEMI-REVERSIBLE HEAT PUMP / ORC



CONSTRUCTION OF THE CARNOT BATTERY



SYSTEM MODELLING



SYSTEM SIMULATION



CONCLUSIONS

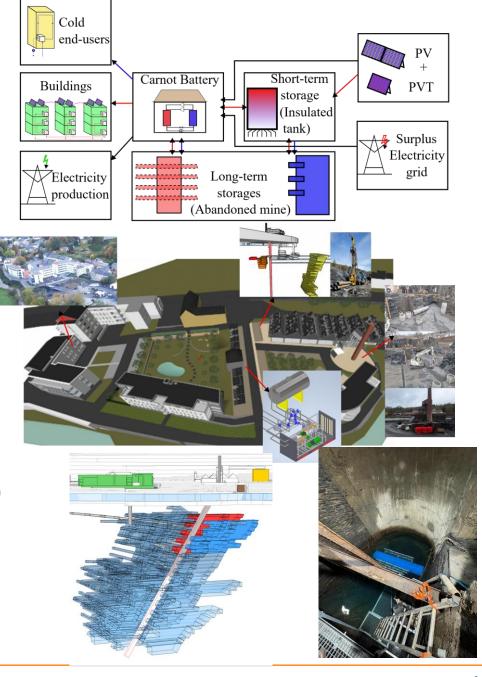


Case study General technical features

- Slate mines in the South of Belgium
- Abandoned since the 90s
- Flooded with 500,000 m³ of water = massive storage
- Residential buildings (50 apartments) with heating/cooling demands
- Local electricity production: 70 kWe photovoltaic (PV) system and a 140 kWth photovoltaic-thermal (PT) collector installation

Heat and cold storage

- ⇒ for covering heating/cooling **demands in buildings**: to increase self-consumption of local electricity (water-to-water heat pump)
- ⇒ For local and grid electricity storage (Carnot battery, Power-to-Heat a Heat Pump and Heat-to-Power an Organic Rankine Cycle)

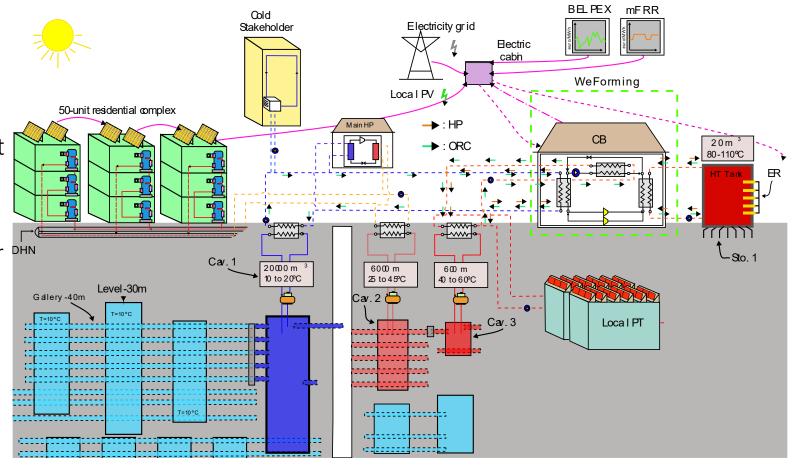




Case study

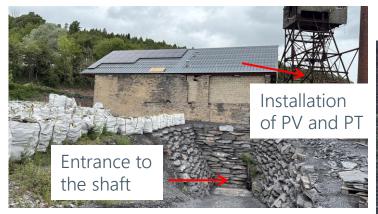
Architecture of the energy system

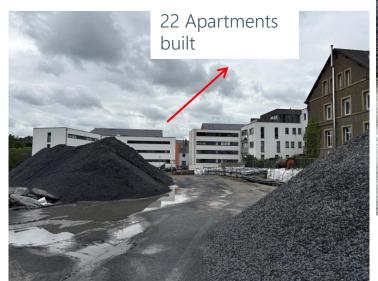
- 20 m³ overground tank at 80-110°C (difficulty to find a submersible pump).
- 600 m³ underground chamber at 40-60°C: PVT or industrial waste heat (40-60°C).
- 20000 m³ underground chamber at 10-20°C: produced by main heat pump and natural generation.
- 6000 m³ underground chamber at 25-45°C : produced by main heat pump.





Case study Actual Progress



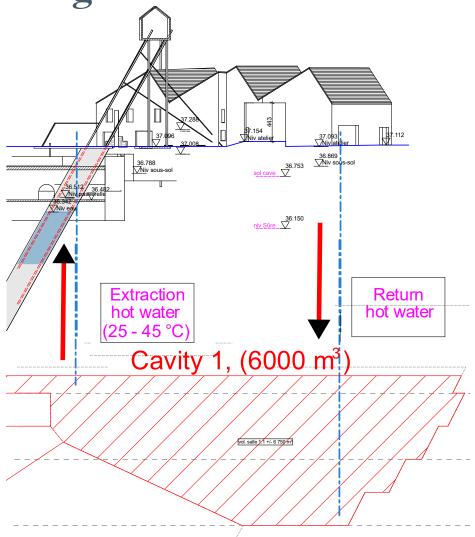


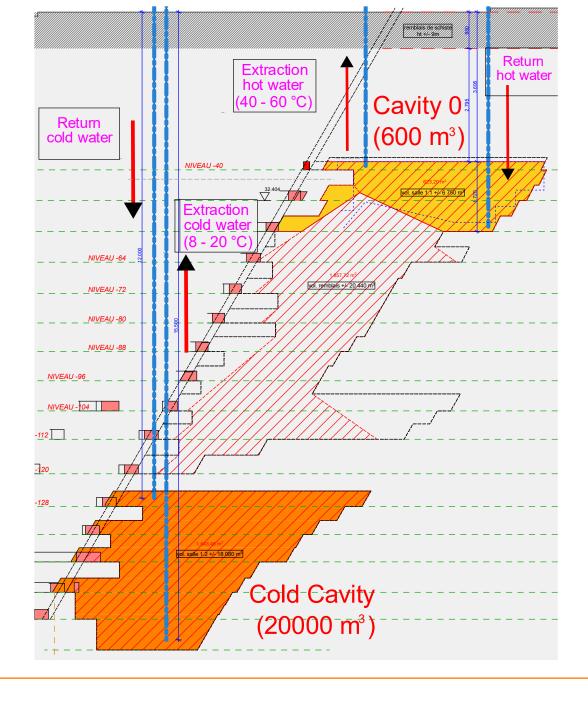




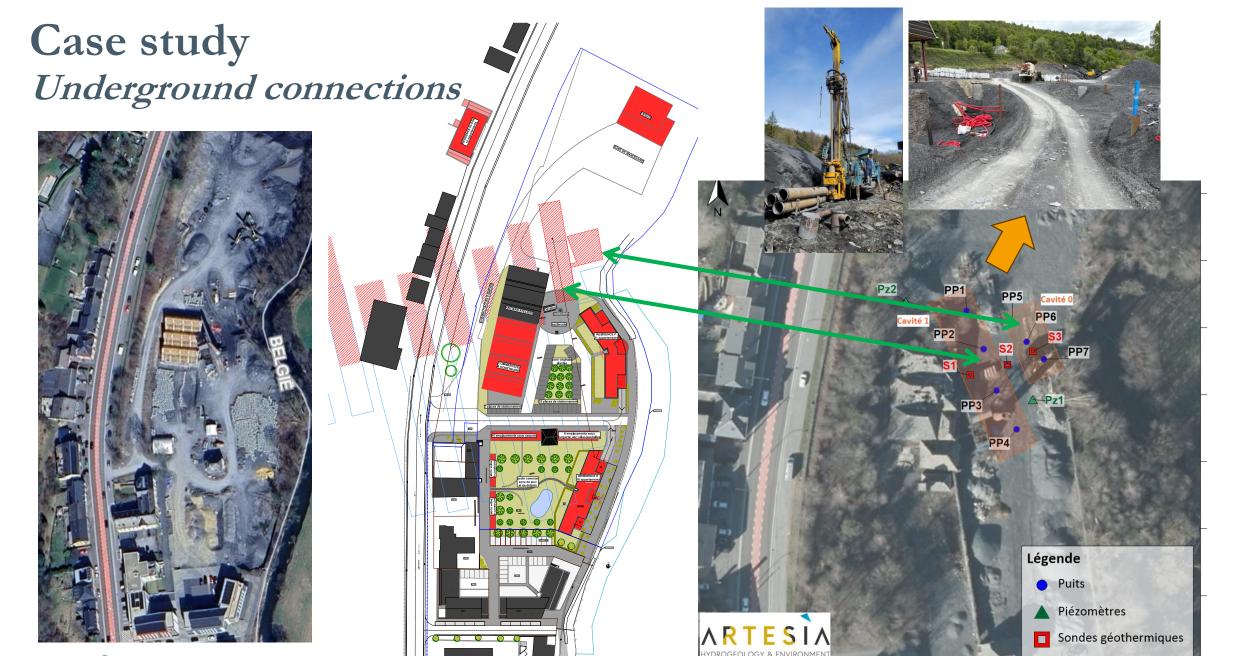


Case study
Underground connections









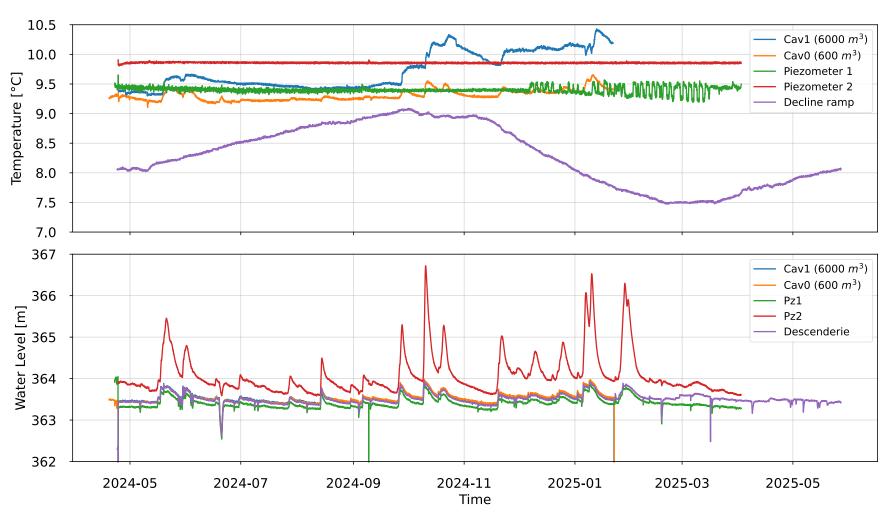


Case study Underground monitoring

Temperature and piezometer sensors in the chambers 0 (600 m3) and 1 (6000 m3). Ready and data for almost one year

 There is no large variation in the temperature. Larger in the decline ramp, which (7.5 − 9)

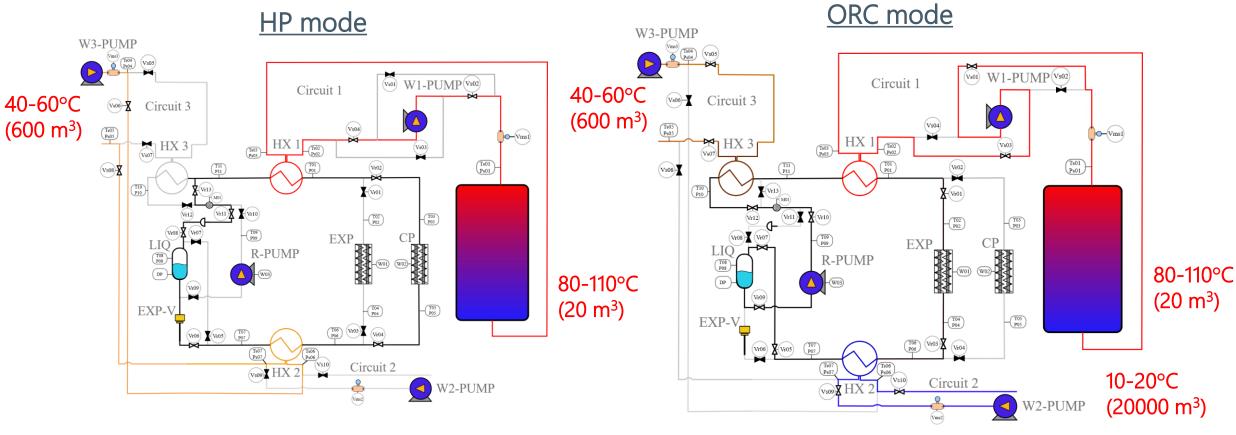
o The water level remains almost fixed with the exception of the Piezometer 2, which oscillates a maximum of 2 meters ✓



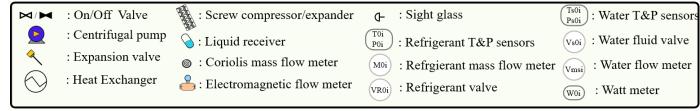


Semi-reversible machine

Architecture



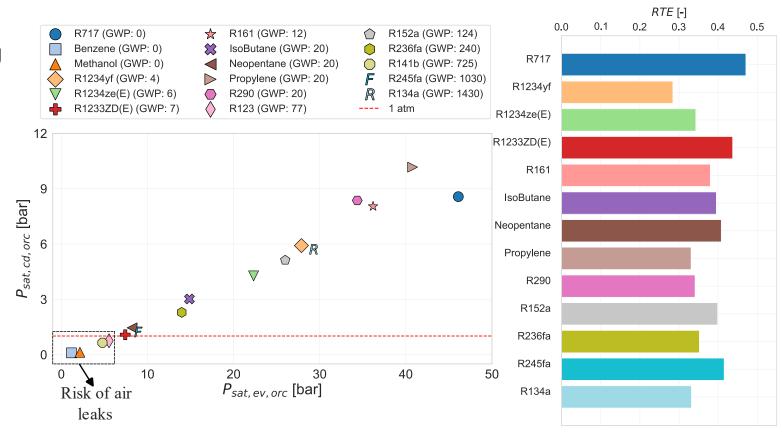
• Semi-reversible: dedicated compressor and expander. All other components are shared





Semi-reversible machine Selection of the working fluid

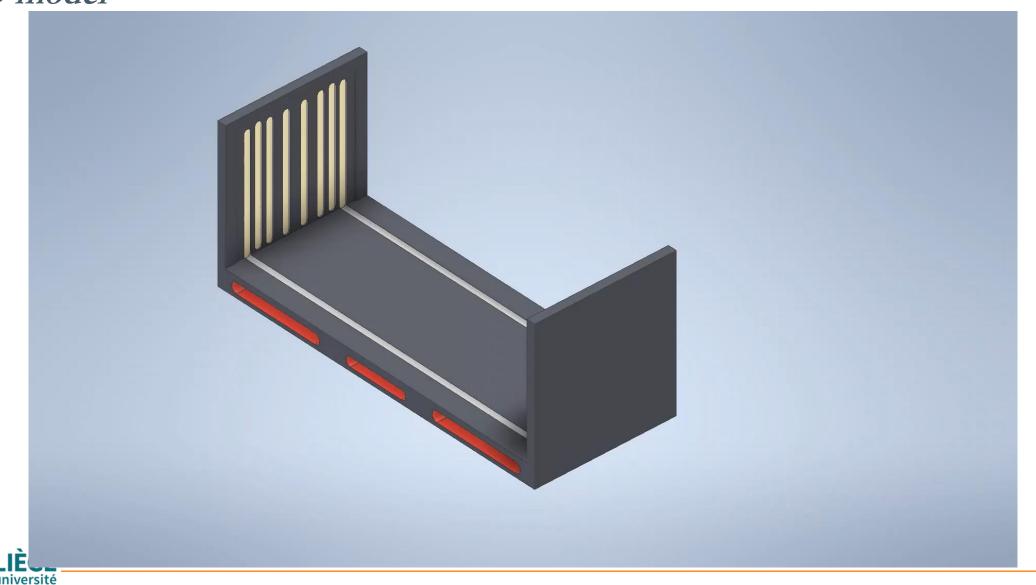
- R1233ZD(E) has been selected considering very high performance for the operational temperatures (Dumont and Lemort, 2020)
 - ✓ Levels of pressure and RTE (using a basic thermodynamic model)
 - ✓ Flammability/toxicity criteria
 - ✓ GWP (<10)
 - ✓ High commercial compatibility





Carnot battery construction 3D model



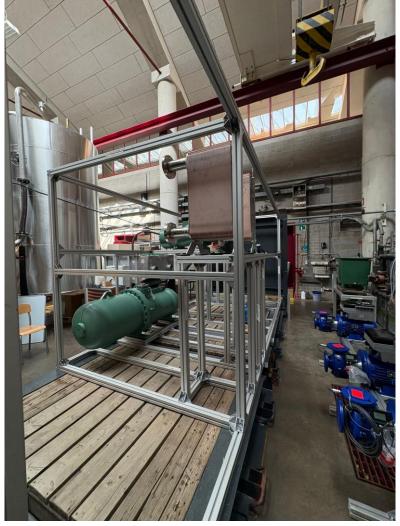


Carnot battery construction

Actual progress









Carnot battery construction Coming work

- Commissioning of the electrical panel (consumption); by mid-August
- Welding and connection of sensors and valves; end of September
- Commissioning of the electrical panel (injection); end of October











Carnot battery construction Common Problems





Charge management → Large charge difference between two modes, general ORC mode present more refrigerant charge than HP mode



Reversible integration of volumetric machine

Operation mode from one mode to another, limited to the maximum torque of the motor/generator



Overheating -> Problems with the electronics of the valves operating at high temperatures



Pump integration → Normally very low efficiency is reported, due to the low Net Positive Suction Head available



Market restrictions → Limited reversible components available in the market



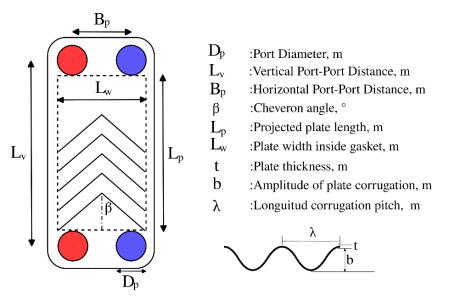
System modeling Why modeling the reversible machine?

- Better predict the **performance in off-design conditions**, across all the operating conditions of the Carnot battery (different water temperatures and different scenarios)
- **Update the sizing of components** proposed by manufacturers, considering off-design conditions: number of plates, etc.
- Evaluation of the **optimal control** for maximizing machine operation efficiency. Develop control for the pumps' speed control, for the expansion valve and for the compressor operation.



System modelling Heat exchangers

- 3 brazed Plate Heat Exchangers (BPHX)
- Multi-zone model
- Iteration on the heat transfer area:

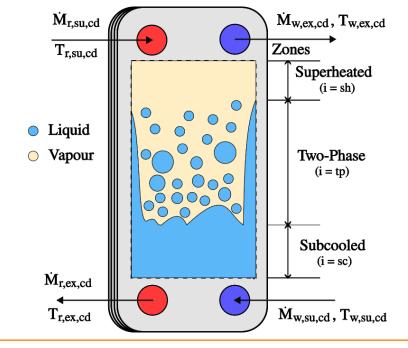


$$Res_{cd} = A_{real,BPHE} - A_{i,BPHE} = A_{real,BPHE} - (A_{sh,BPHE} + A_{tp,BPHE} + A_{sc,BPHE})$$

- Pressure drops taken into account
- Computation of fluid charge (void fraction model):

$$M_{r,cd} = M_{r,sc,cd} + \int_{x=0}^{x=1} M_{r,tp,i,cd} dx + M_{r,sh,cd}$$

Preheater could comprise a 2-phase zone





System modelling Expander

• HSEL8591-110Y-40 from Bitzer ($V_s = 1275 \ cm^3$)

-- Error ±5%

3.0

5.0

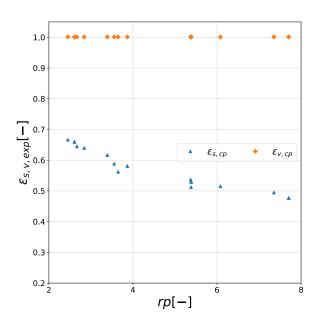
4.5

4.0 گل 3.5 كل

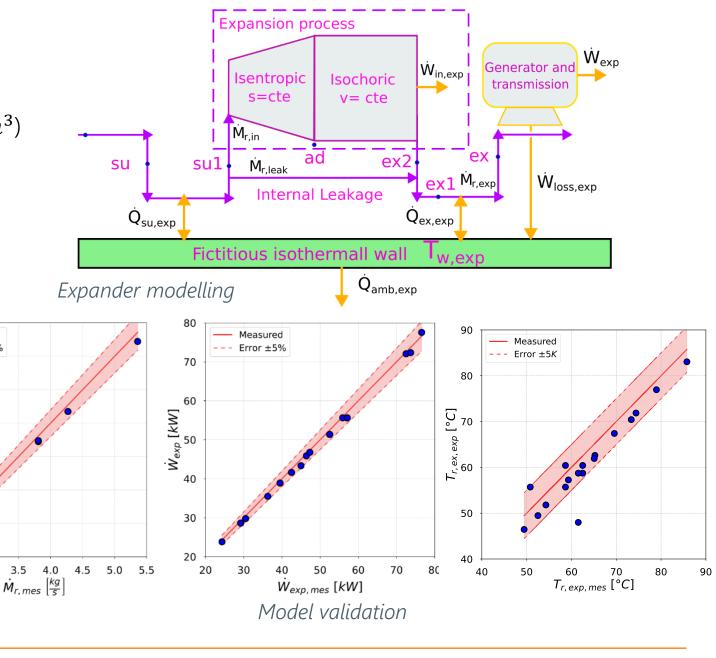
3.0

2.5

- Grey-box model (10 parameters)
- 18 points at fixed speed at 50 Hz (online)



Information provided by manufacturer





System modelling Compressor

- Model of Bitzer: CSH2T9573-240Y-35D ($V_s = 4026 \ cm^3$)
- Frequency drive FRW-240+4: speed control from 30 to 60 Hz

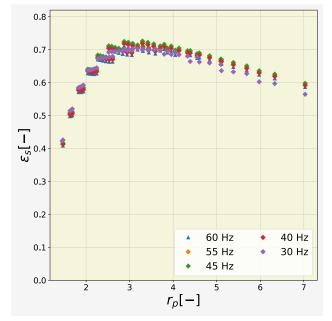
Measured

 $\dot{M}_{r, cp, mes} \left[\frac{kg}{s} \right]$

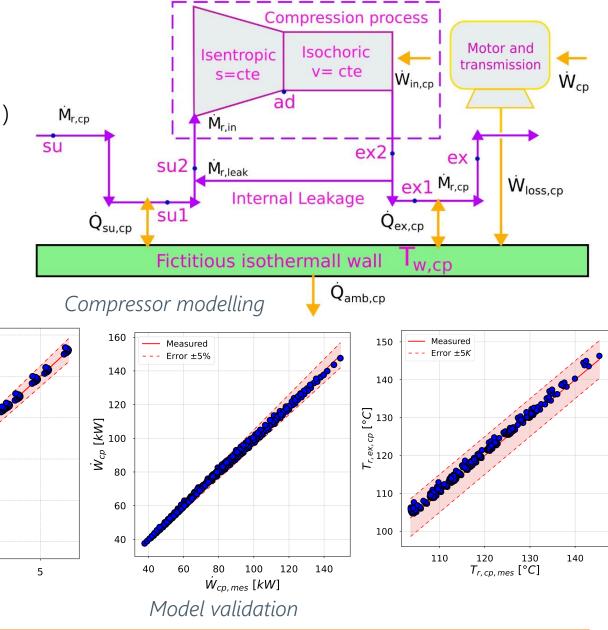
--- Error ±5%

 $\dot{M}_{r,\,cp}\left[\frac{kg}{s}\right]_{\Phi}$

• 275 data points (online)



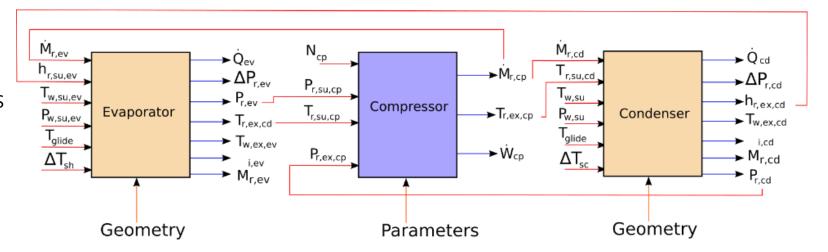
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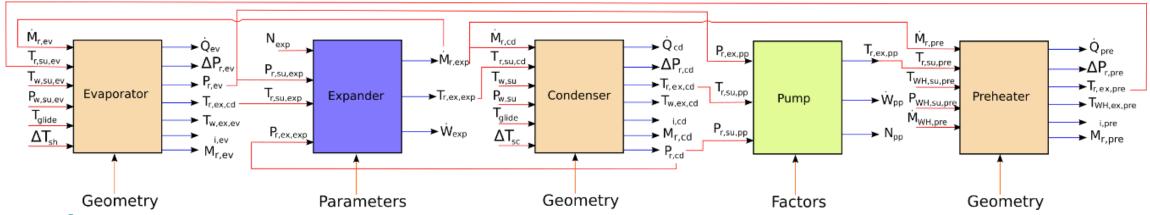
System modelling

Whole system

 Heat pump: iteration on 2 pressures and 5 pressure drops (7 iteration variables)



• ORC: iteration on 2 pressure, 7 pressure drops and the enthalpy at the outlet of the preheater (10 iteration variables

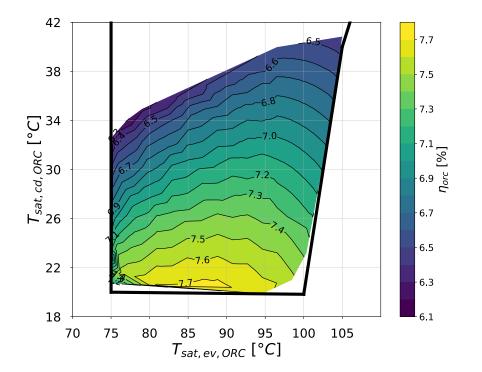


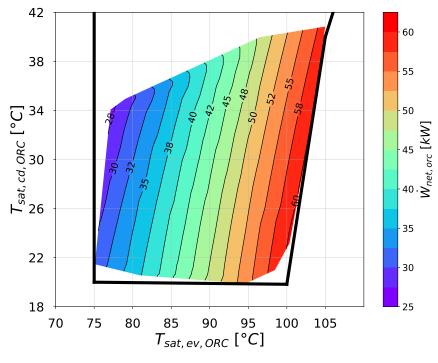
System simulation Performance maps - ORC

 $\dot{W}_{net,orc} = \dot{W}_{exp} - \dot{W}_{pp,orc} - \sum \dot{W}_{pp,i,sf}$

 $\eta_{orc} = rac{\dot{W}_{net,orc}}{\dot{Q}_{ev}}$

- Operational map for the possible conditions in the demonstrator site (50°C)
- Maximum efficiency obtained at the design point
- > ORC efficiency ranges from 7.8% to 6.1% for the possible operational conditions
- > Envelope Limitation imposed by the chosen generator

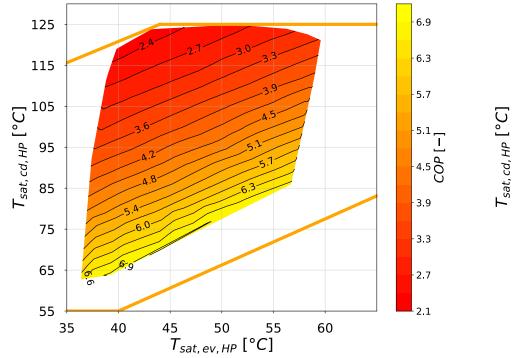


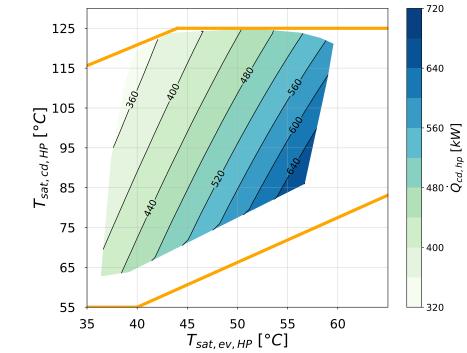




System simulation Performance maps - HP

- Operational map for the possible conditions in the demonstrator site
- The COP ranges from 6.9 to 2.1 for the possible operational conditions $COP = \frac{V}{\dot{W}_{cp} + \sum \dot{W}_{pp,i,sf}}$ Provided the possible operational conditions
- ➤ Envelope Limitation imposed by the chosen motor

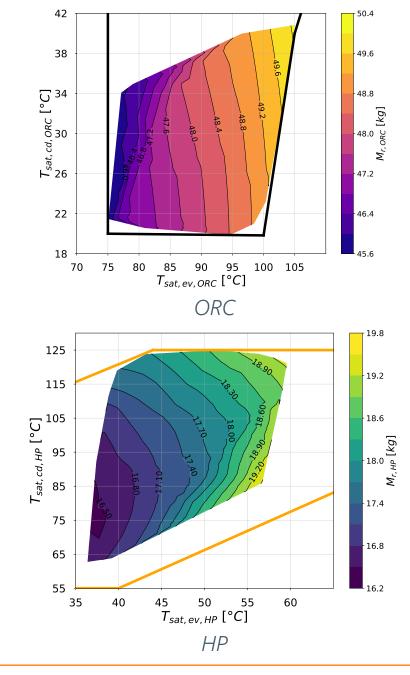






System simulation Refrigerant charge

- Larger charges in ORC vs HP (200%...) because :
 - ✓ Large liquid zone after the pump in ORC
 - ✓ Higher temperatures in HP (lower densities)
 - ⇒ Importance of charge management in dual-mode systems
 - ⇒ Important role of the **liquid receiver**
- Larger oil circulation ratio in ORC vs HP, 5% vs 3% within the refrigerant mass flow rate



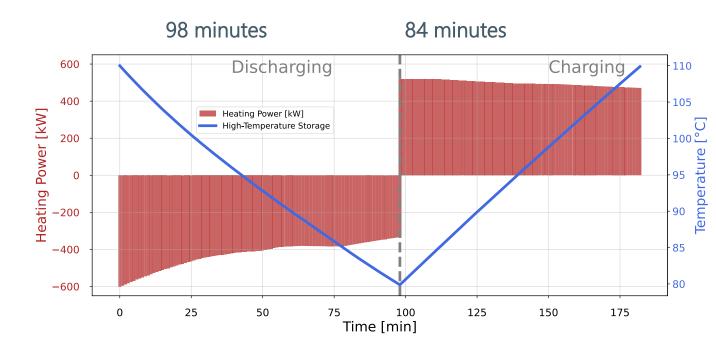


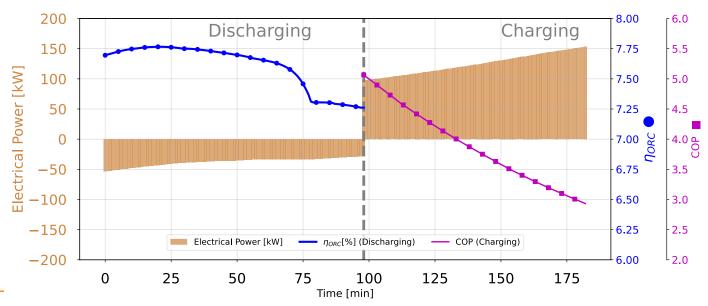
System simulation Integration in the case study

- Overground 20 m³ hot storage:
 - > SOC=100% at 110°C
 - ➤ SOC=0% at 80°C
- No modelling of the stratification (fully mixed)
- ORC efficiency: 7.76% to 7.28%
- Heat pump COP: 5.06 to 2.93

•
$$RTE = \frac{\int_{\tau_{ini}}^{\tau_{dis}} E_{net,ORC} d\tau}{\int_{\tau_{dis}}^{\tau_{char}} E_{net,HP} d\tau} = 29.02\%.$$

 Could be increased by integrating largergrade waste heat or decreasing the storage temperature (CB "degenerates", large volumes for storing the same electricity, consider LCOS)





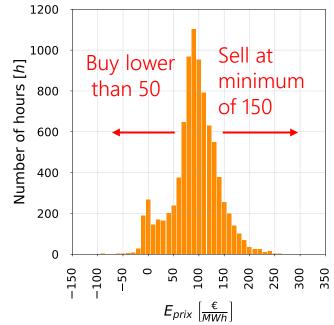
System simulation What does it mean?

- A RTE value of almost 30% can be seen as follows (note that this value can be improved with higher "waste heat temperatures")
- It is also possible to participate in the flexibility market as a frequency restoration service: upward (ORC mode); downward (HP Mode)
- The same CB can be used in different storage volumes to increase discharge and charge times, unlike electrochemical batteries, where the number of batteries must be increased

Daily ahead market: price distribution Belgium 2023

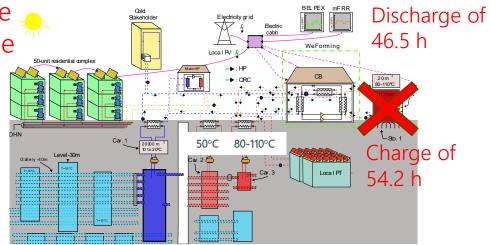
To generate revenues





To increase the storage capacity







Conclusions

- Case study:
 - The demonstrator case, with a 20 m³ sensible storage, should achieve an RTE of 29.02%
 - The size of storage could be increased (600 m³ vs 20 m³), increasing the discharge and charging time.
 - Prototype under construction will be tested by early 2026:
 - Increase the rate of self-consumption from RES. Absorbing electricity and converting it into heat, which can be supplied to the heat network or stored in different volumes.
 - Semi-reversible HP/ORC module has been designed, and a model has been built to investigate its performance in offdesign conditions
 - Larger charge of refrigerant in ORC mode, compared to HP mode
- General
 - Different waste heat can be integrated and employed in the module:
 - storing heat to produce electricity,
 - Upgrade the temperature to be reused in an external process (possible to produce vapour by a flash tank configuration)
 - Further available waste heat temperature (<100°C) will increase the RTE, and then the revenues that can be obtained





Many thanks for your attention!

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