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Fault Detection for an ATES Triplet Under Future Climate Scenarios

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INTRODUCTION

ATES Triplet reduces grid electricity use by utilising on-site renewable energy and Aquifer Thermal Energy Storage. It operates with a **hot well**, a **cold well** and a **buffer well** that balances flows and prevents thermal pollution of the supply wells. **Future climate projections** indicate **higher outdoor temperatures** and **increased solar irradiation**, raising cooling demand and lowering on-site cold generation. These shifts may reduce stored cold energy and limit the system's ability to meet **peak loads**. This study evaluates Triplet performance under the **KNMI dry and high CO_2 scenario** and identifies key indicators for early **fault detection** to support **long term operation**.

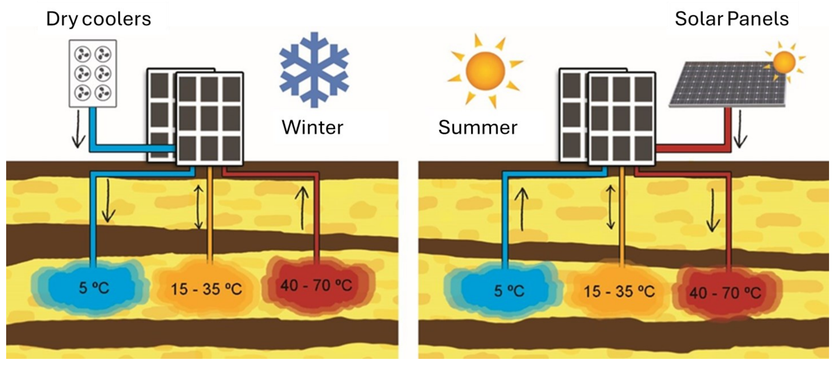


Figure 1. Conceptual diagram showing the basic operation of the ATES Triplet system.

METHODOLOGY

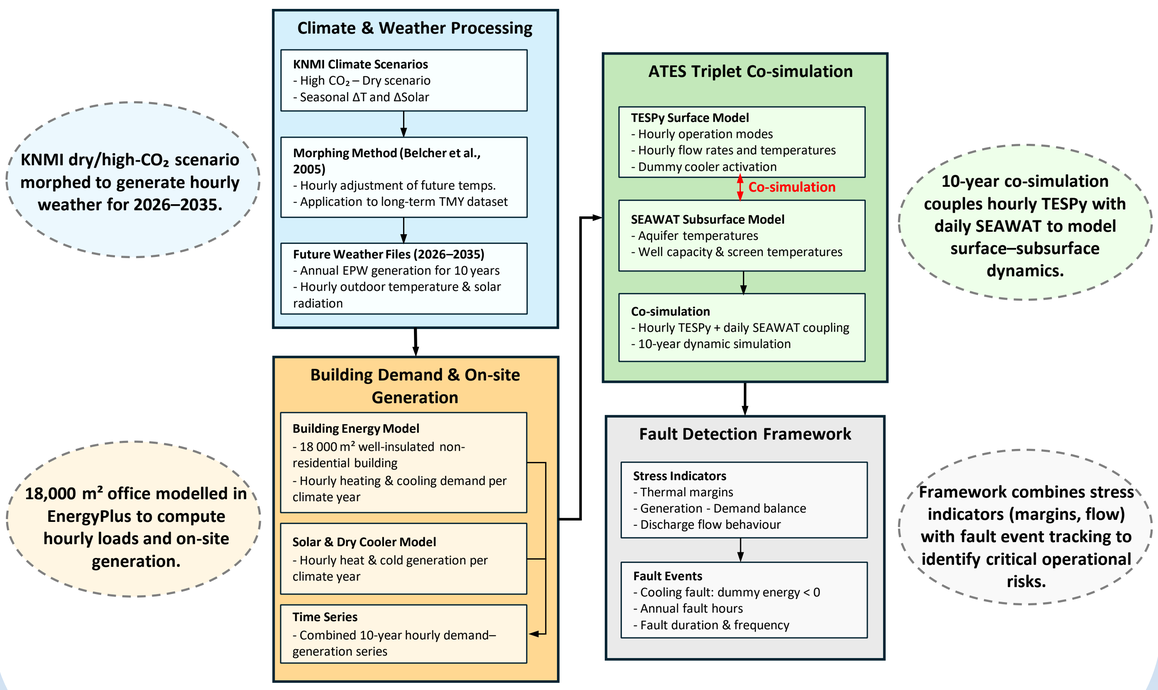


Figure 2. Methodology of the study.

FUTURE CLIMATE - MORPHING METHOD

The morphing approach modifies both the mean and the daily amplitude.

1. Shift - Adjust the mean: $T'(t) = T(t) + \Delta T$

2. Strech - Adjust the day-night difference : $T'(t) = \bar{T} + r \cdot [T(t) - \bar{T}]$

3. Combined morphing: $T'(t) = \bar{T}_f + r \cdot [T(t) - \bar{T}_c]$

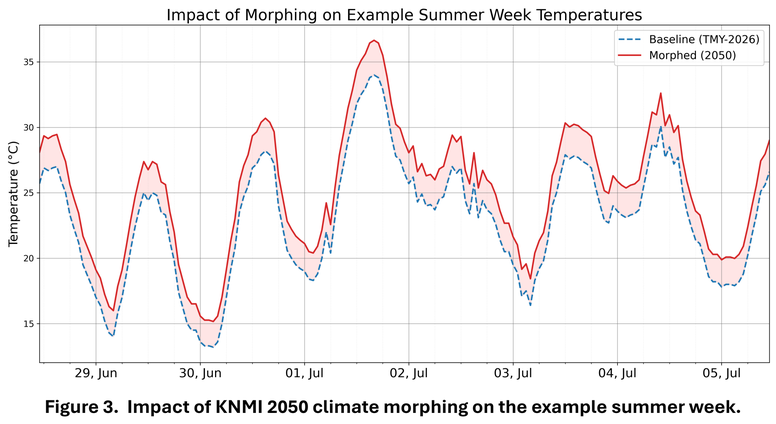


Figure 3. Impact of KNMI 2050 climate morphing on the example summer week.

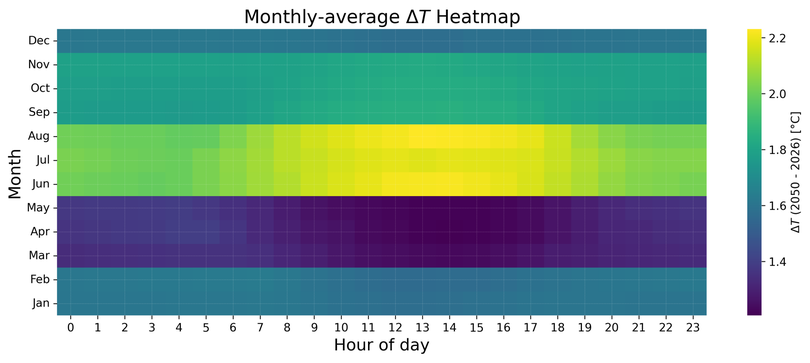
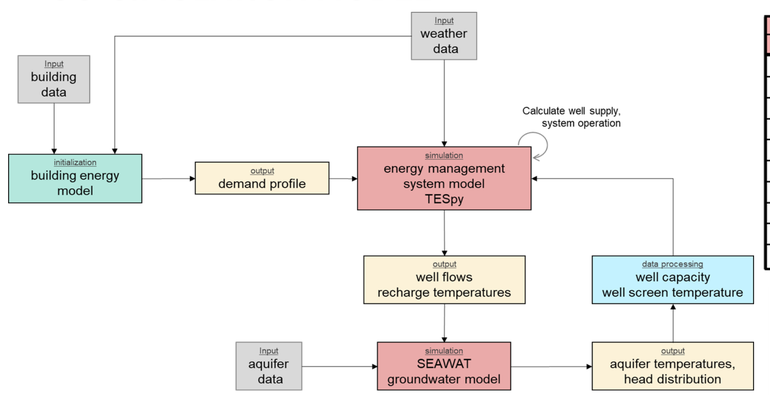


Figure 4. Monthly-average temperature increase (ΔT) heatmap of morphing effect.

CO-SIMULATION MODEL



Heating Sources & Storage

MODES	Heating		Storage	
	Solar	ATES	Cold	Heat
MODE H1	●		●	●
MODE H2	●			●
MODE H3a	●	●	●	
MODE H3b	●	●	●	
MODE H4	●	●		
MODE H5	●		●	
MODE H6	●			
MODE H7a		●	●	
MODE H7b		●	●	
MODE H8		●		

Cooling Sources & Storage

MODES	Cooling		Storage	
	Dry C.	ATES	Cold	Heat
MODE C1	○		○	○
MODE C2	○		○	
MODE C3a	○	○		○
MODE C3b	○	○		○
MODE C4	○	○		
MODE C5	○			○
MODE C6	○			
MODE C7a		○		○
MODE C7b		○		○
MODE C8		○		

MODES	Cold Demand		Heat Demand		Storage	
	Dry C.	ATES	Solar	ATES	Cold	Heat
MODE H&C1	○	○	○	○		
MODE H&C2-a	○	○	○	○		○
MODE H&C2-b	○	○	○	○		○
MODE H&C2-c	○	○	○	○		○

MODES	Storage	
	Cold	Heat
MODE S1	○	○
MODE S2	○	
MODE S3		○

Figure 4. SEAWAT (Subsurface) - TESpy (Surface) Co-Simulation Model and Operation Modes

RESULTS

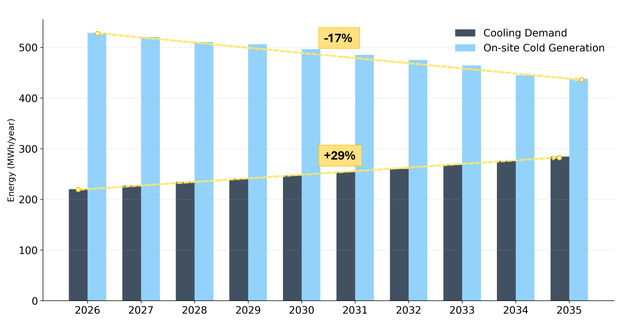


Figure 5. Annual cooling demand and on-site cold generation under future climate years.

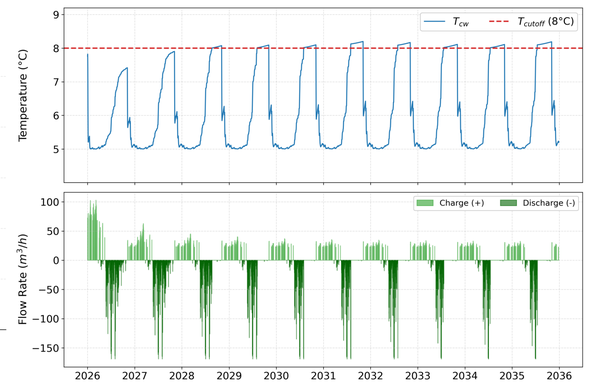
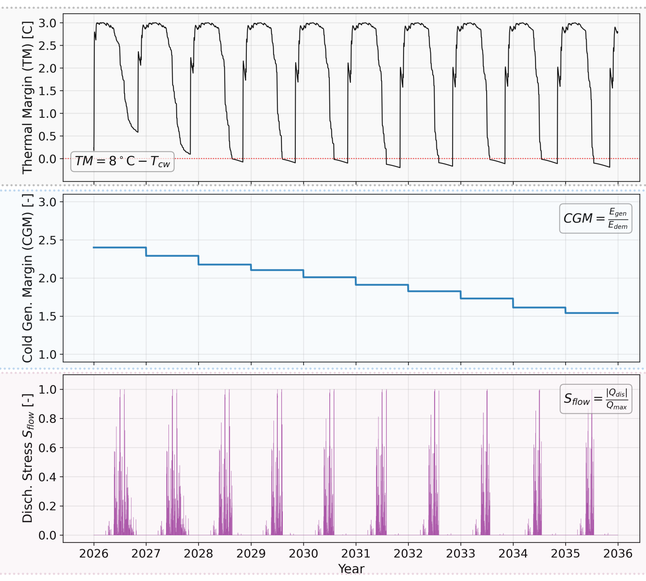


Figure 6. Cold well temperature and flow rates.

STRESS INDICATORS

Thermal Margin (TM): Proximity to the operational limit *8 °C*. **(Lower = Critical Risk)**



Cold Generation Margin (CGM): Ratio of on-site generation to demand. **(Lower = Supply Deficit)**

Discharge Flow Stress (S_flow): Discharge intensity relative to well capacity. **(Higher = Increased Stress)**

Figure 7. Stress indicators.

FAULT EVENTS

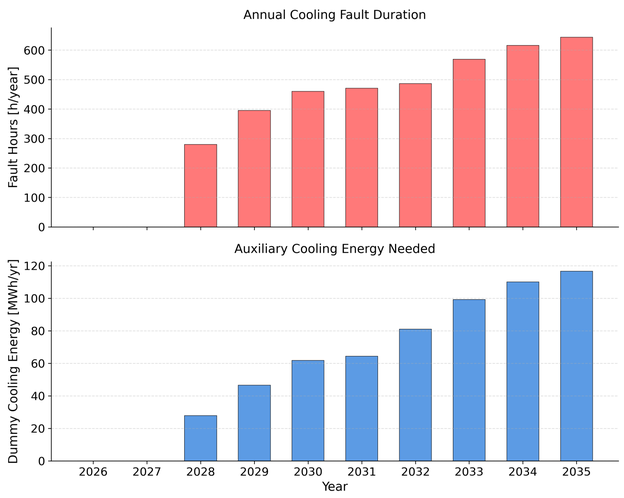


Figure 8. Annual fault hours and dummy cooling energy under future climate years (2026–2035).

Faults start appearing around **2028** and become increasingly frequent and severe toward 2035 under the future climate scenario. Fault hours rise to about **650 h/year by 2035**, while dummy cooling energy need reaches nearly **120 MWh/year**. Together, these trends indicate growing cooling shortages and a rising reliance on additional cooling energy or increased storage capacity.

CONCLUSIONS

- **Future climate conditions** project **higher ambient temperatures** and **lower on-site cold generation**, raising **operational stress** on the ATES Triplet.
- **The stress indicators** show narrowing **thermal margins**, declining **generation balance** over the decade.
- The **TESPy–SEAWAT co-simulation** captures how surface operation and subsurface operates dynamically under these conditions.
- **Cooling faults** begin to appear around **2028** and become clearer toward **2035**, reaching about 650 fault-hours and requiring nearly 120 MWh/year of auxiliary cooling.
- Maintaining stable operation may require **additional cooling energy** or **increased storage resilience**.
- Future work will examine well flow-rate limits, short-term storage options and passive measures that reduce cooling demand.

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