

Underwater Data Center: Zero-Energy Cooling for a Greener Future

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Introduction

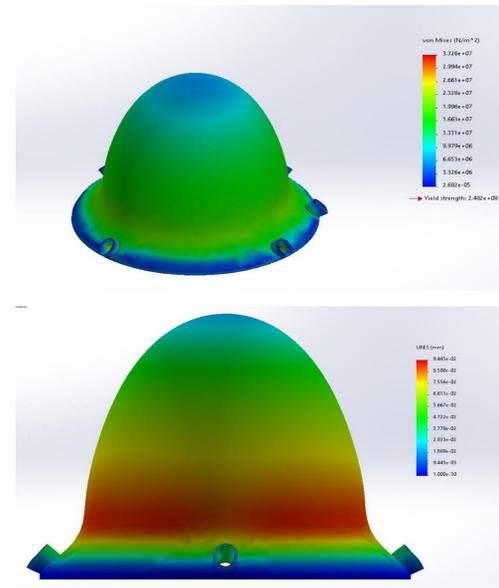
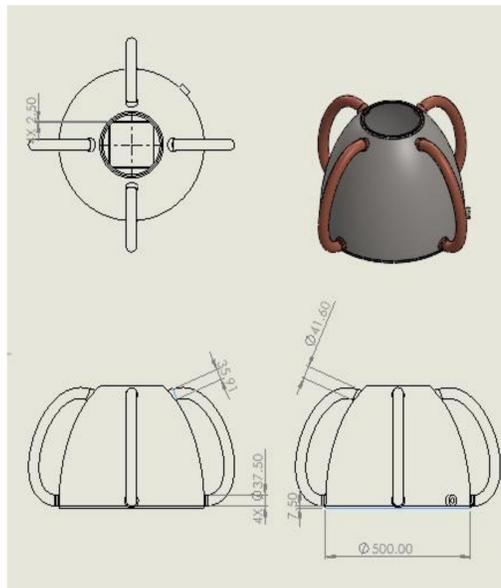
Problem Statement:

Cooling systems consume nearly 40% of the energy used in traditional data centers, driving over \$100 billion in operational costs each year and producing significant carbon emissions. With rising data demands, this approach is becoming both economically and environmentally unsustainable. This project proposes a modular underwater data center that uses seawater for passive cooling, featuring real-time monitoring and corrosion-resistant materials to deliver a cost-effective, low-latency solution for coastal areas.

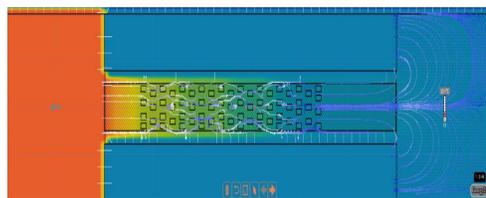
Constraints	Specifications
Complexity of the power system	Total surface area of the pipes \geq 0.1 m ²
High-durability materials due to hydrostatic pressure and aggressive marine environment	Temperature monitoring with an accuracy of ± 2 C
Limited budget < 8000 SAR	Sacrificial anodes (aluminum) to prevent material corrosion for at least 5 years
High heat generation	Dissipate 100% of heat
	Coolant temperature should not exceed 5C ambient sea temperature
	0% energy used for cooling
	24/7 efficient heat management
	Maintain servers' surrounding temperature below 27 C

Prototype Design

- CAD Design
- Stress and Deformation Analysis



- Heat Transfer Simulation



- Internal components

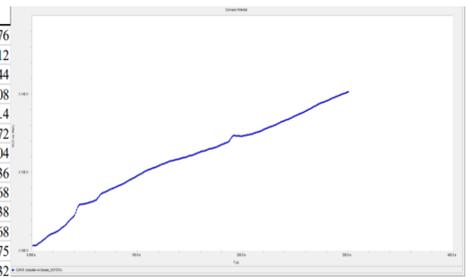


Function	Prototype component
Durability & Corrosion protection	SS 316L + Sacrificial anodes
Real-time monitoring	Temperature sensors
Heat generation	PCB
Heat transfer	Copper-nickel pipes with packed bed and thermal fans boost circulation efficiency.

Testing / Validation

Results after one hour: Aluminum alloy OPC vs. SCE

Time (min)	Fluid Temp In (°C)	Fluid Temp Out (°C)	Heat Load (W)	Q_cond (W)
0	47.5	25.5	8800	28963.76
5	47.79	25.71	8833.32	29069.12
10	48.08	25.92	8866.68	29174.44
15	48.38	26.12	8900	29306.08
20	48.67	26.33	8933.32	29411.4
25	48.96	26.54	8966.68	29516.72
30	49.25	26.75	9000	29622.04
35	49.54	26.96	9033.32	29727.36
40	49.83	27.17	9066.68	29832.68
45	50.12	27.38	9100	29938
50	50.42	27.58	9133.32	30069.68
55	50.71	27.79	9166.68	30175
60	51	28	9200	30280.32



- **Temperature Stability:** Maintained a temperature rise of $\sim 4.8^\circ\text{C}$ between inlet and outlet, within the 5°C design limit.
- **Heat Handling:** Effectively managed up to 10 kW of heat load with no performance drop.
- **Conduction & Convection:** Achieved efficient heat transfer through both conduction and convection, validated by stable heat load and Q_{cond} data.
- **Sensors:** Integrated real-time temperature sensors ensured accurate monitoring and control.
- **Sacrificial Anodes:** Aluminum anodes were tested for cathodic protection.
- **Testing Method:** OCP tests confirmed effective protection, with 1.44 kg of anodes designed to last over 9 years.

Conclusion

The project achieved zero-energy cooling by transferring heat from the fluid to the pipes (conduction) and then to seawater (convection). It handled 10 kW of heat, stayed below the 5°C limit, and proved reliable, efficient, and eco-friendly.