A Novel Modular Framework for Unified Data Center Cooling Virtual Testbed

Viswanathan Ganesh[1], **Hongjun Li**[1], **Michael Maloney**[1], **Wangda Zuo**[1]

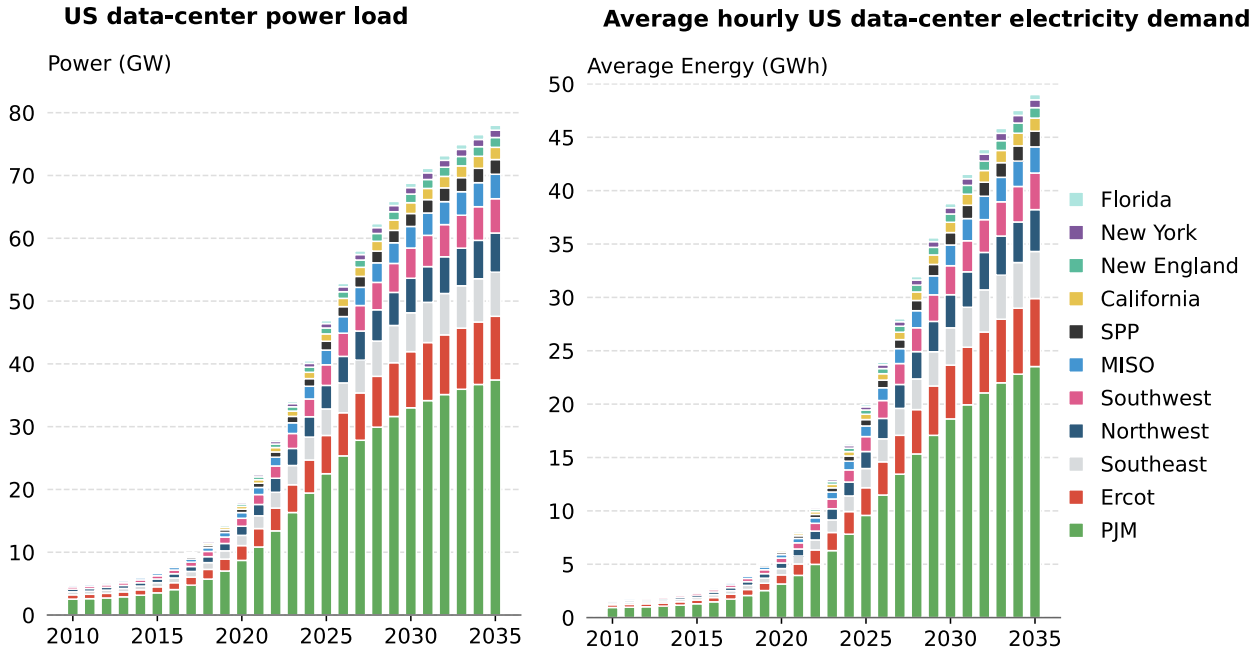
[1] Pennsylvania State University, University Park, PA, USA

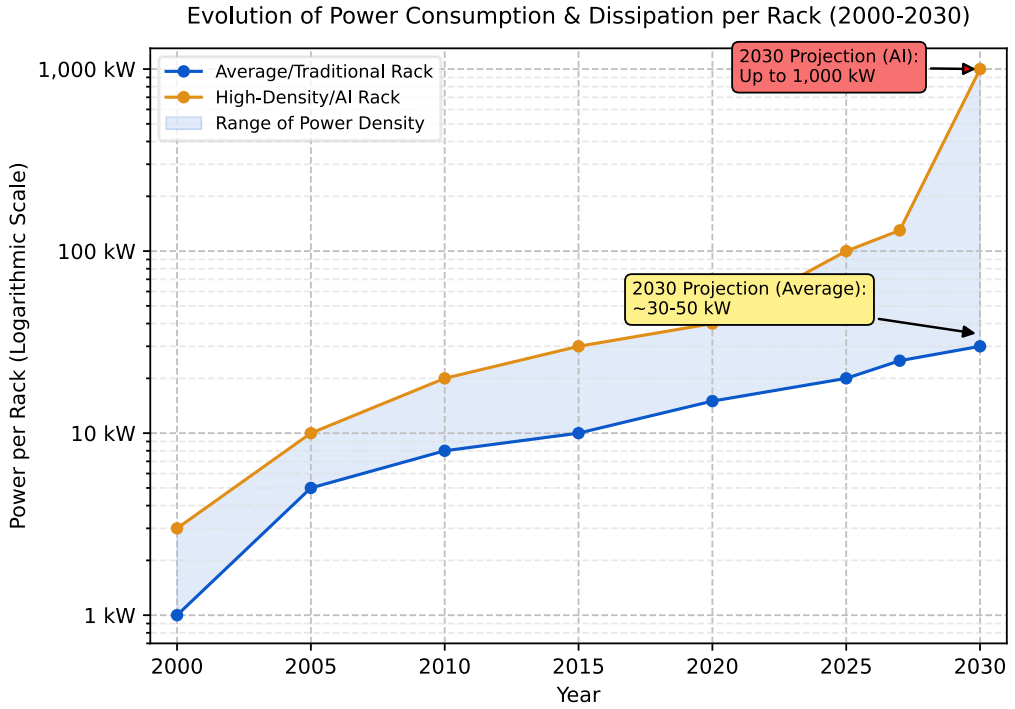
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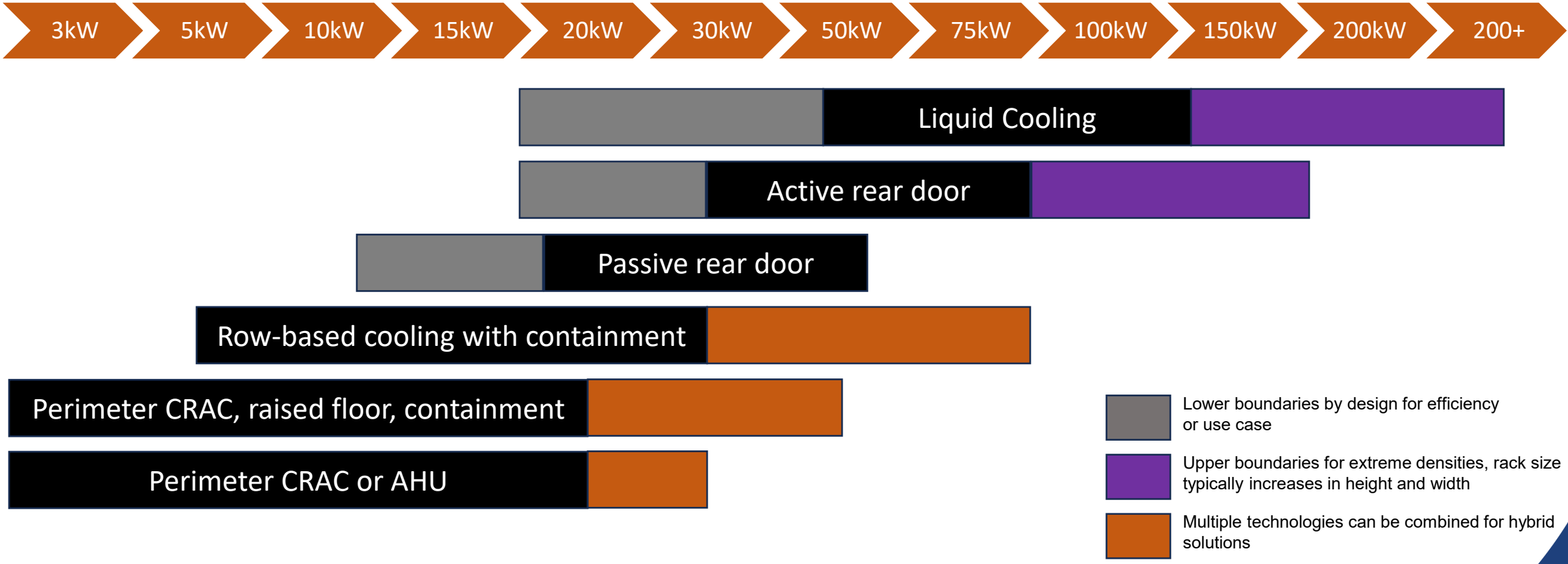
Introduction





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Whitespace Cooling Delivery



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ASHRAE Thermal Guidelines for White Space

Air Cooled

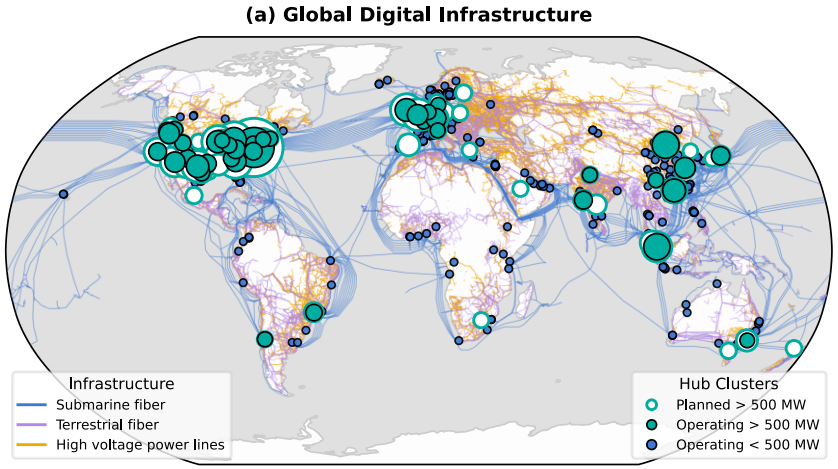
Class	Dry-Bulb Temp (℃)	Humidity Range (%)
A1	15 to 32	8 to 80
A2	10 to 35	8 to 80
A3	5 to 40	8 to 85
A4	5 to 45	8 to 90
B	5 to 35	8 to 80
C	5 to 40	8 to 80

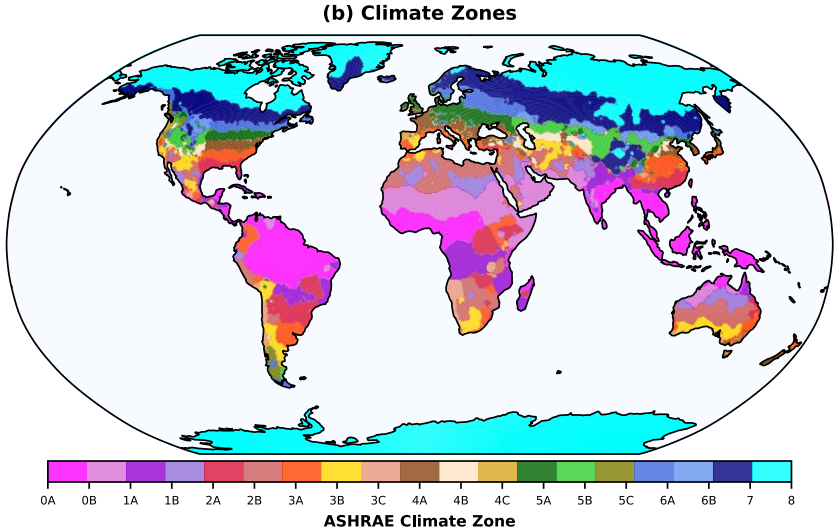
Liquid Cooled

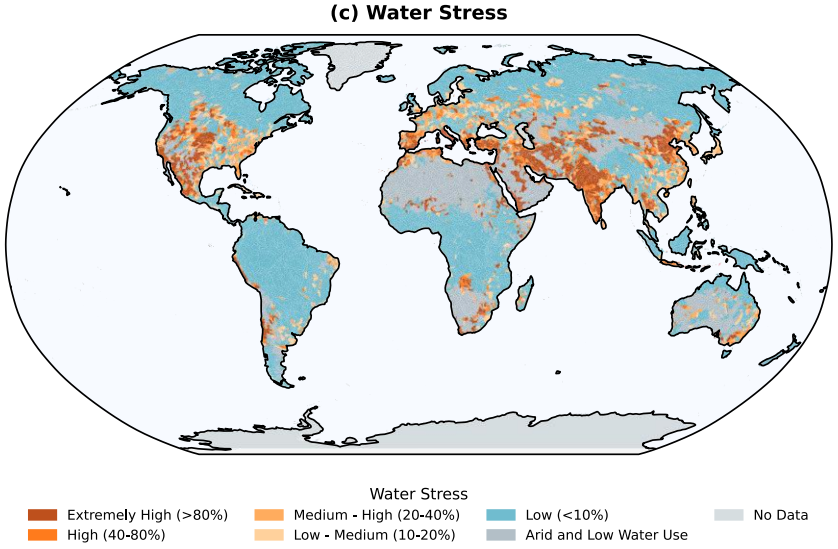
Class	Facility Water Supply (℃)
W17	2 to 17
W27	2 to 27
W32	2 to 32
W40	2 to 40
W45	2 to 45
W+	>45

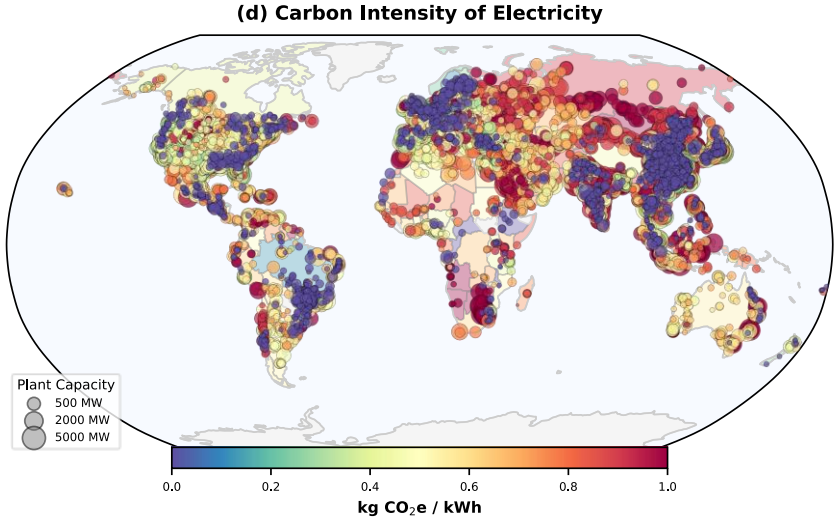
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Global Outlook





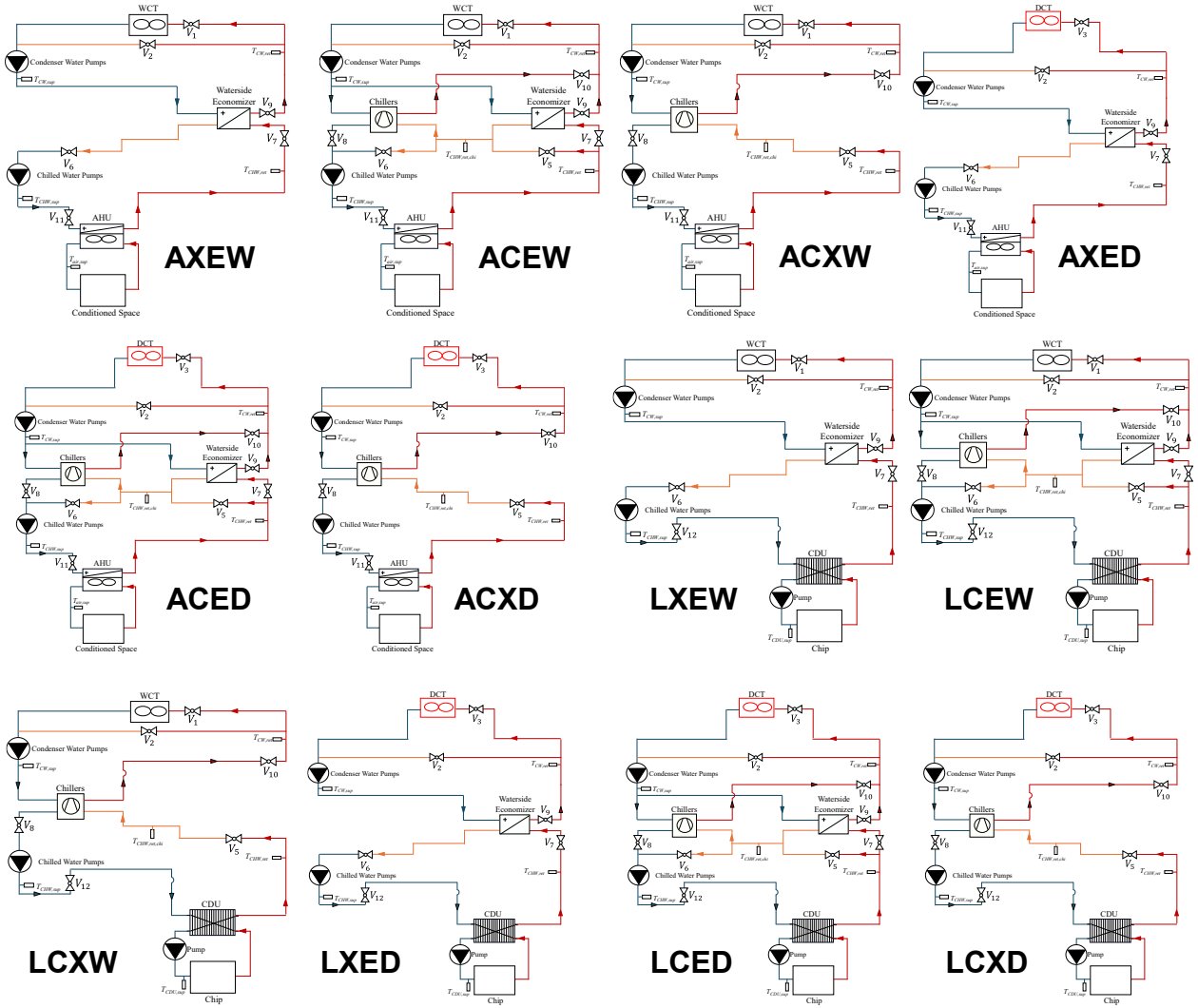


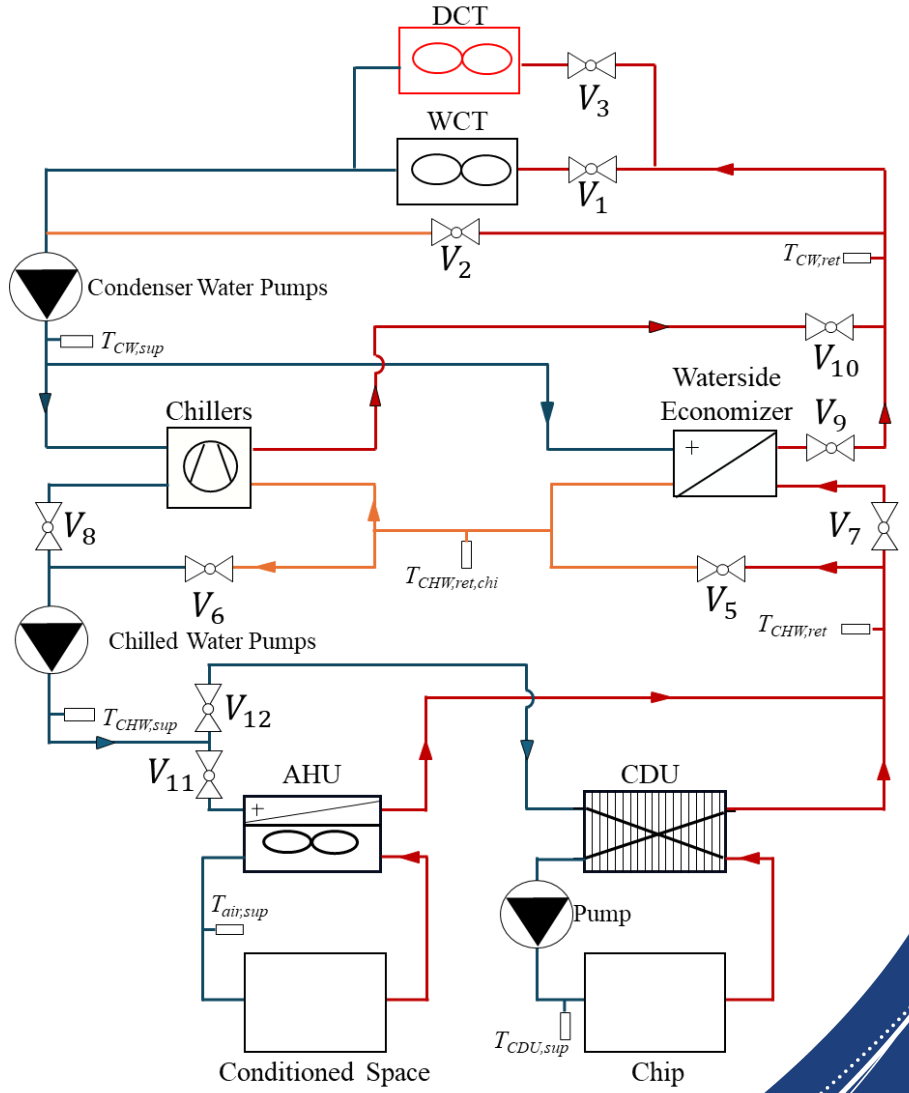


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Cooling System: Overview





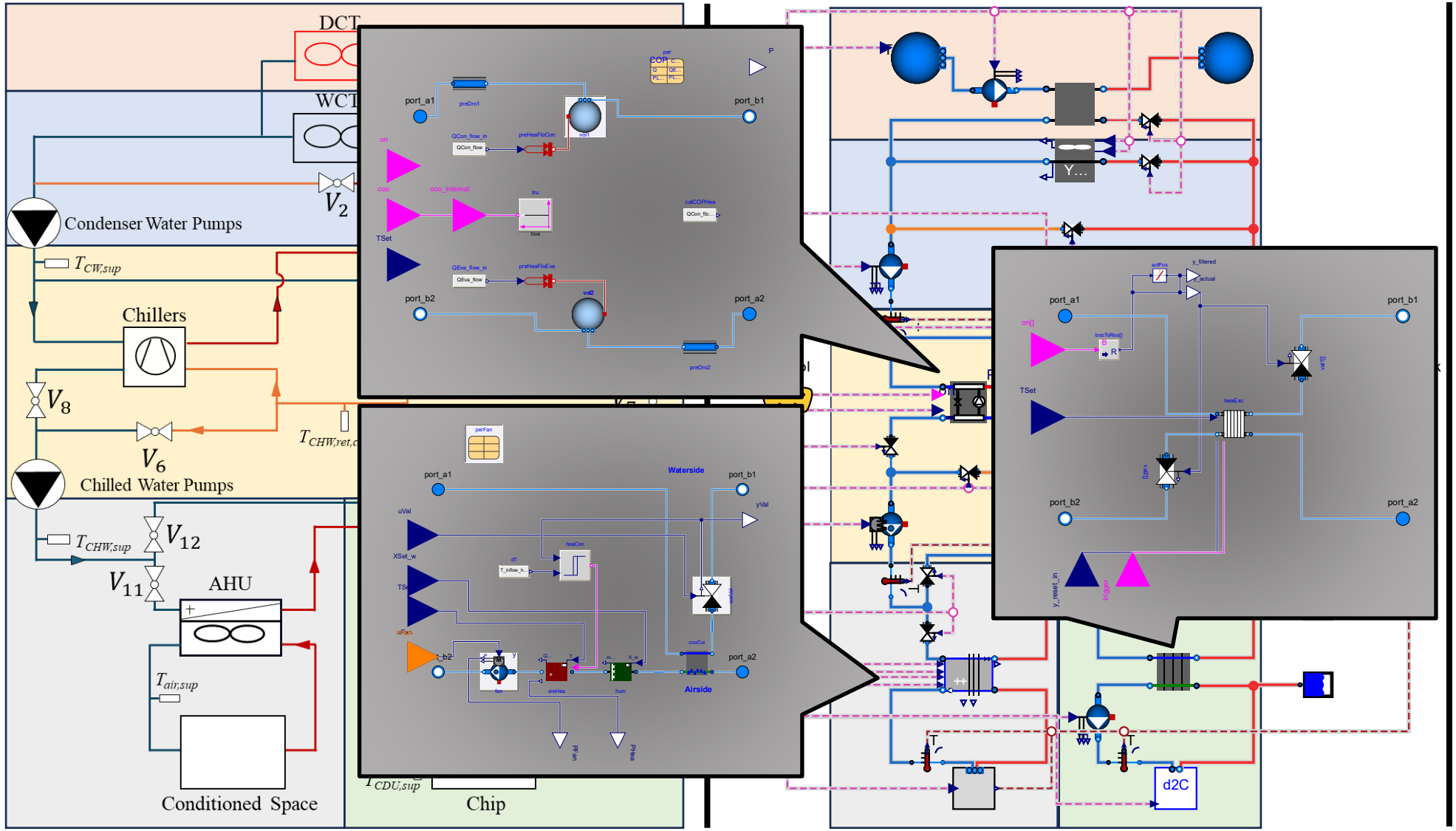
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Motivation

- Develop a unified virtual test bed for air and liquid cooling systems to enable rapid testing and evaluation.
- Introduce the evaluation metrics and constraints.
- Automate the process from development to report generation.

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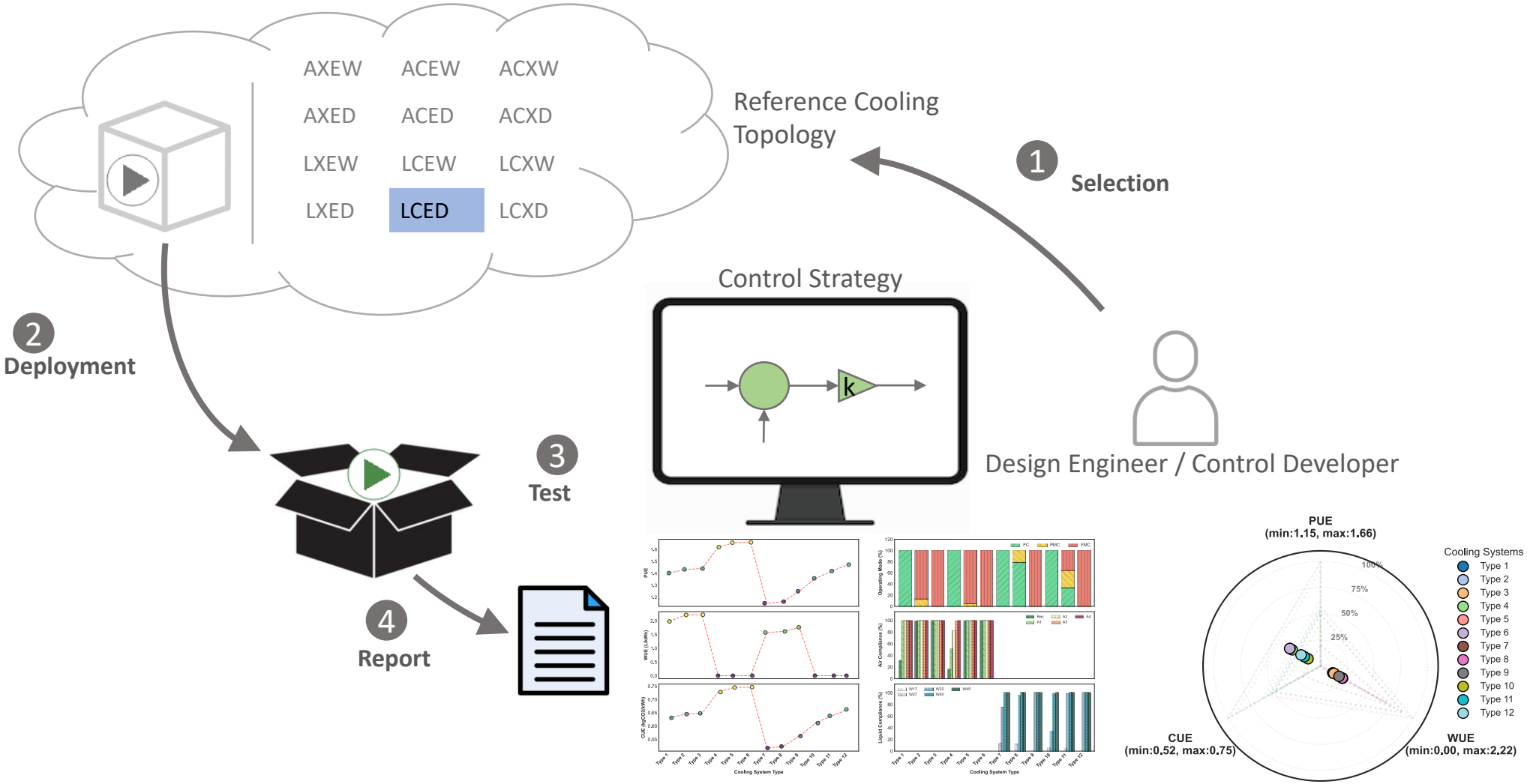
Implementation



TestBed

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Workflow Automation



V. Ganesh, H. Li, M. Maloney, W. Zuo 2026. "DCOPTEST: A Novel Unified Virtual Testbed for Data Center Cooling Systems." *SoftwareX*. 36. pp. 103073.

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Case Study 1

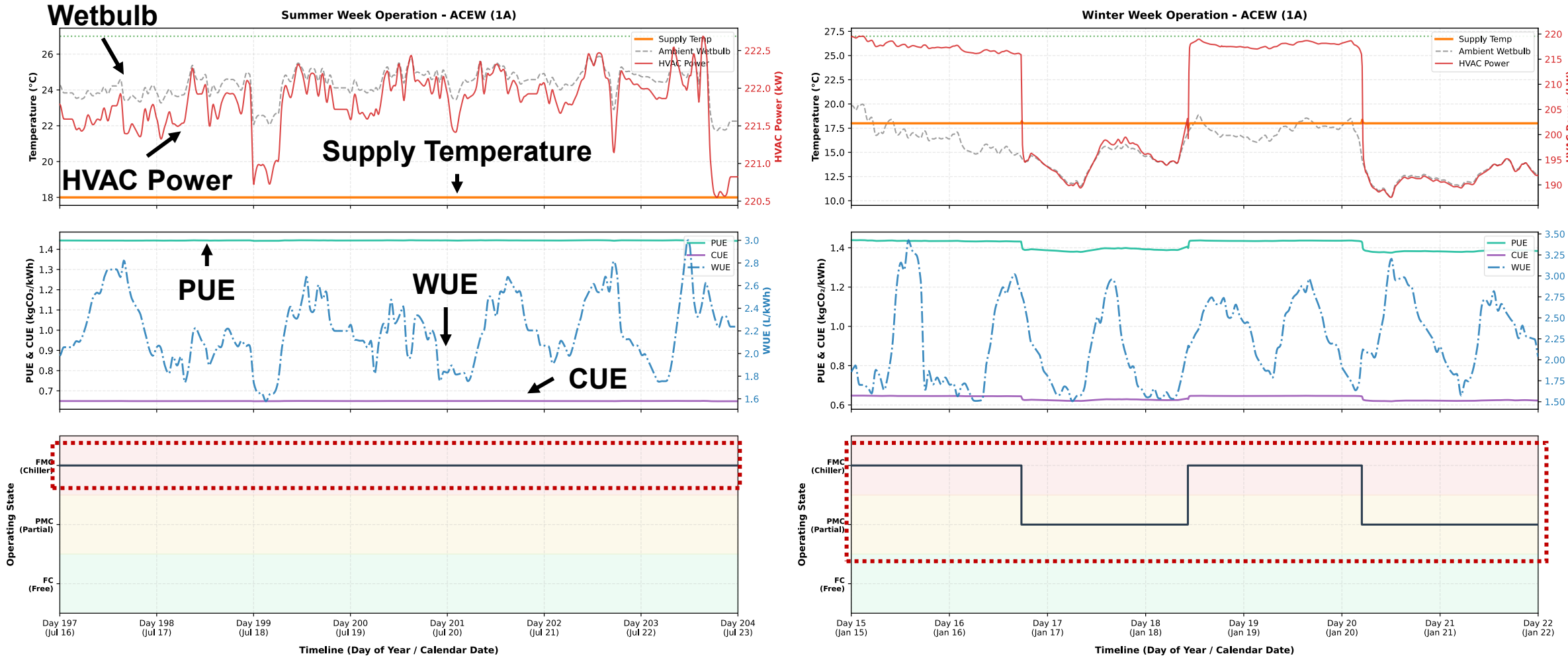
Simulation Dynamics, Annual Performance in Miami, FL

Climate Zone: 1A (Very Hot, Humid)

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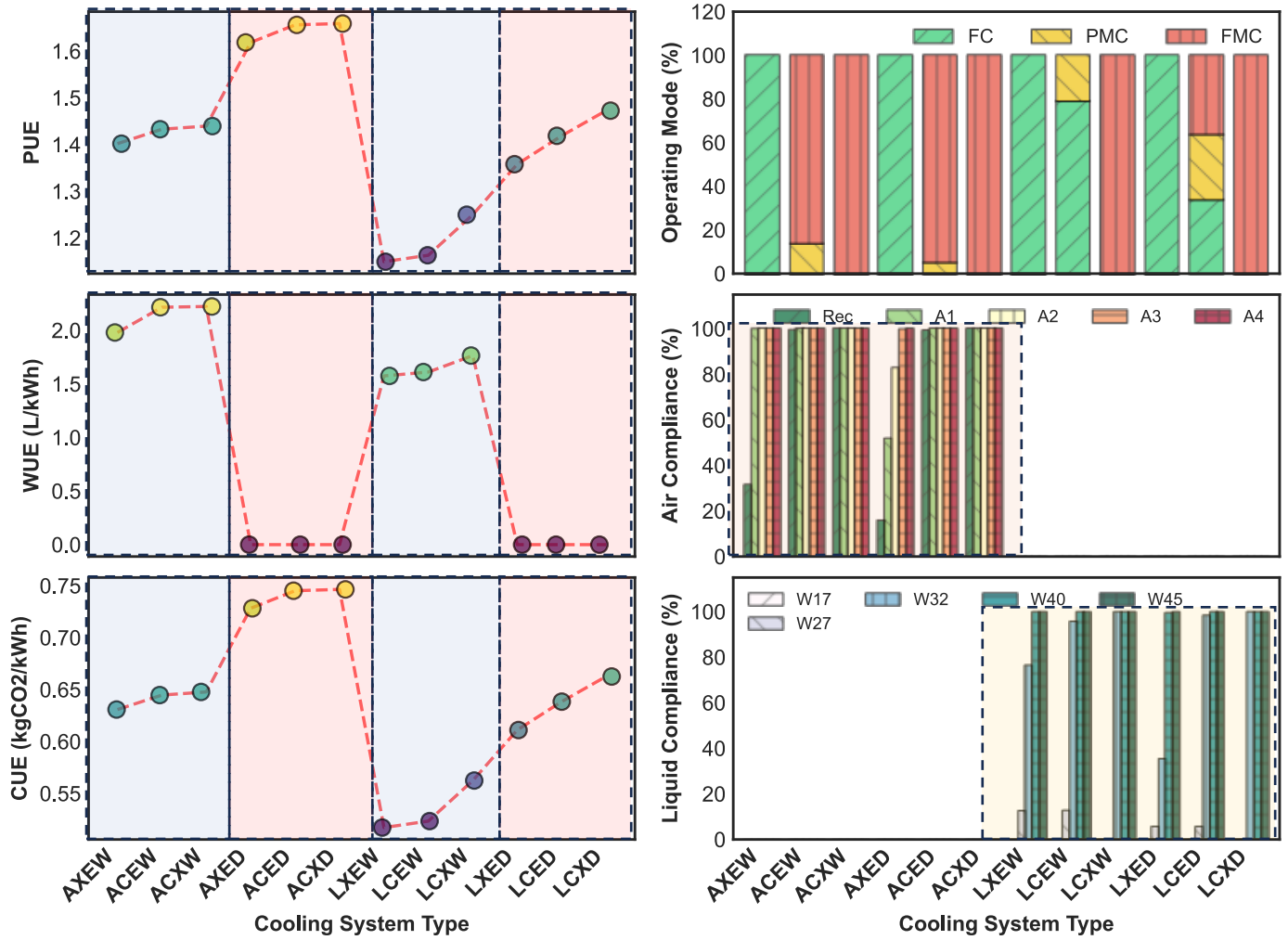
Case Study (Miami, FL) (CZ: 1A)



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Case Study (Miami, FL) (CZ: 1A)

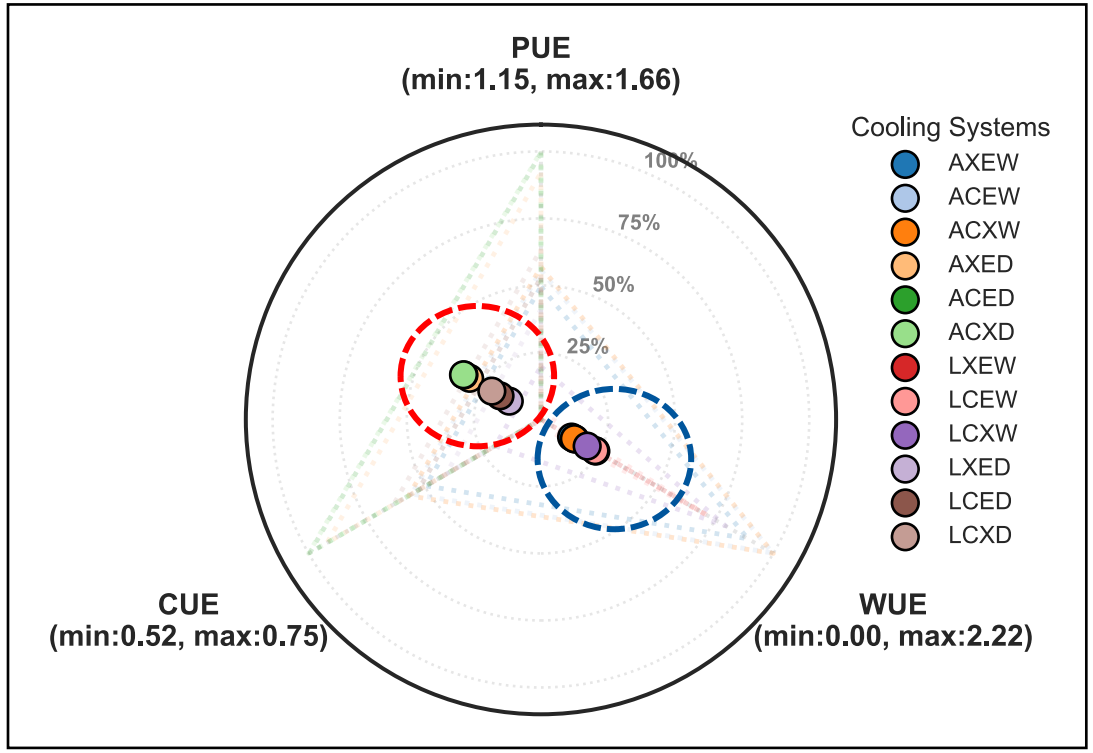


V. Ganesh, H. Li, M. Maloney, W. Zuo 2026. "DCOPTEST: A Novel Unified Virtual Testbed for Data Center Cooling Systems." *SoftwareX*. 36. pp. 103073.

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Case Study (Miami, FL) (CZ: 1A)



PUE = Total Facility Energy / IT Equipment Energy

WUE = Total Facility Water / IT Equipment Energy

CUE = Total Facility Carbon / IT Equipment Energy

V. Ganesh, H. Li, M. Maloney, W. Zuo 2026. "DCOPTEST: A Novel Unified Virtual Testbed for Data Center Cooling Systems." *SoftwareX*. 36. pp. 103073.

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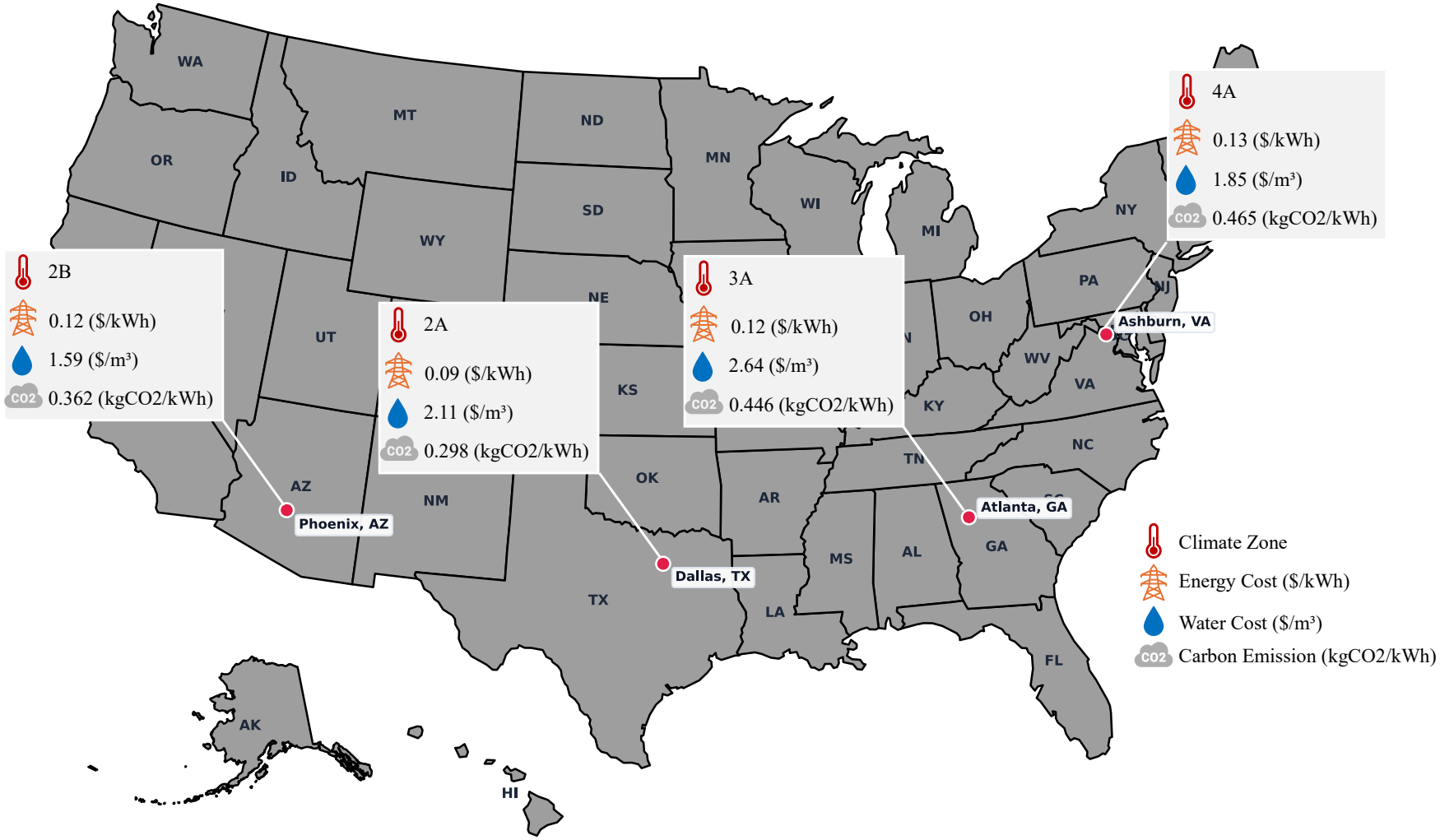
Case Study 2

Top **4** Data Center hubs in USA and Introduction to **Nexus** Metric

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Case Study: Top 4 Hubs in USA

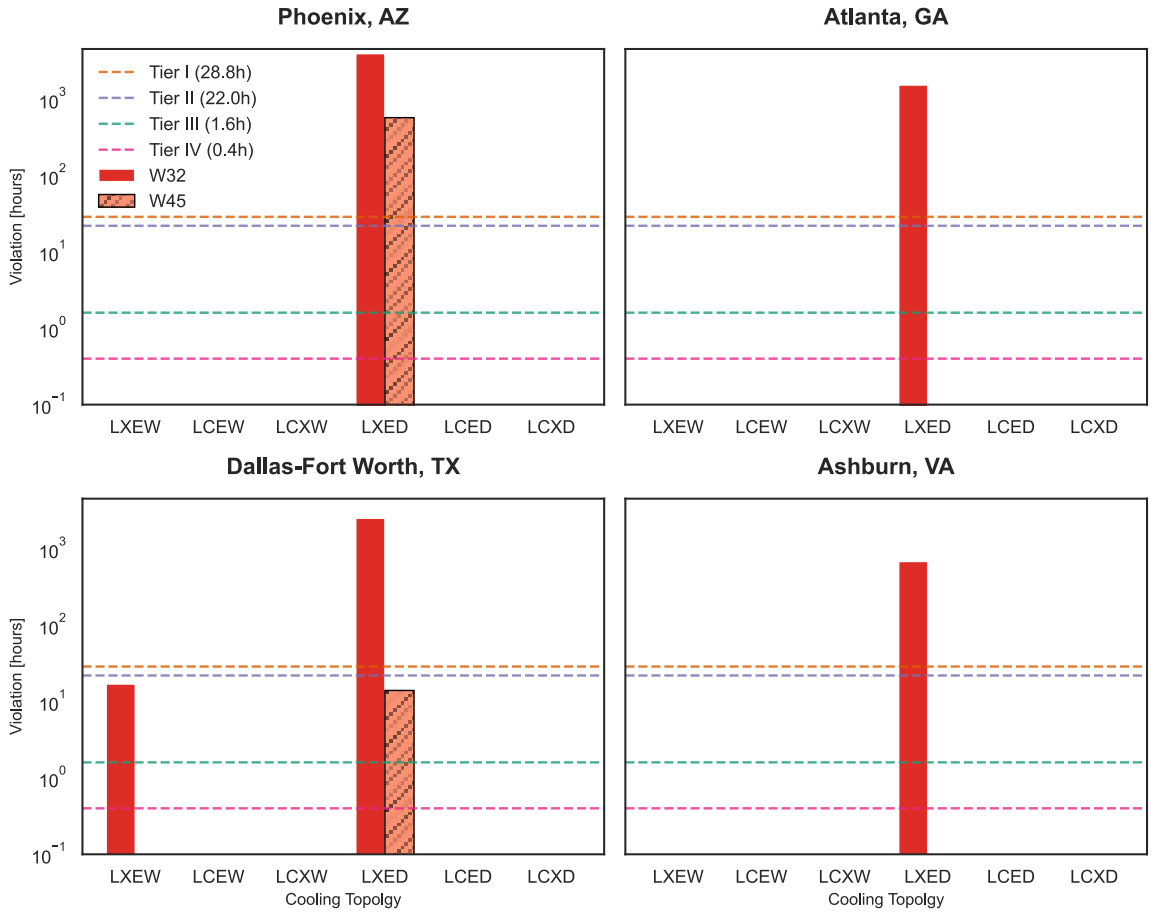


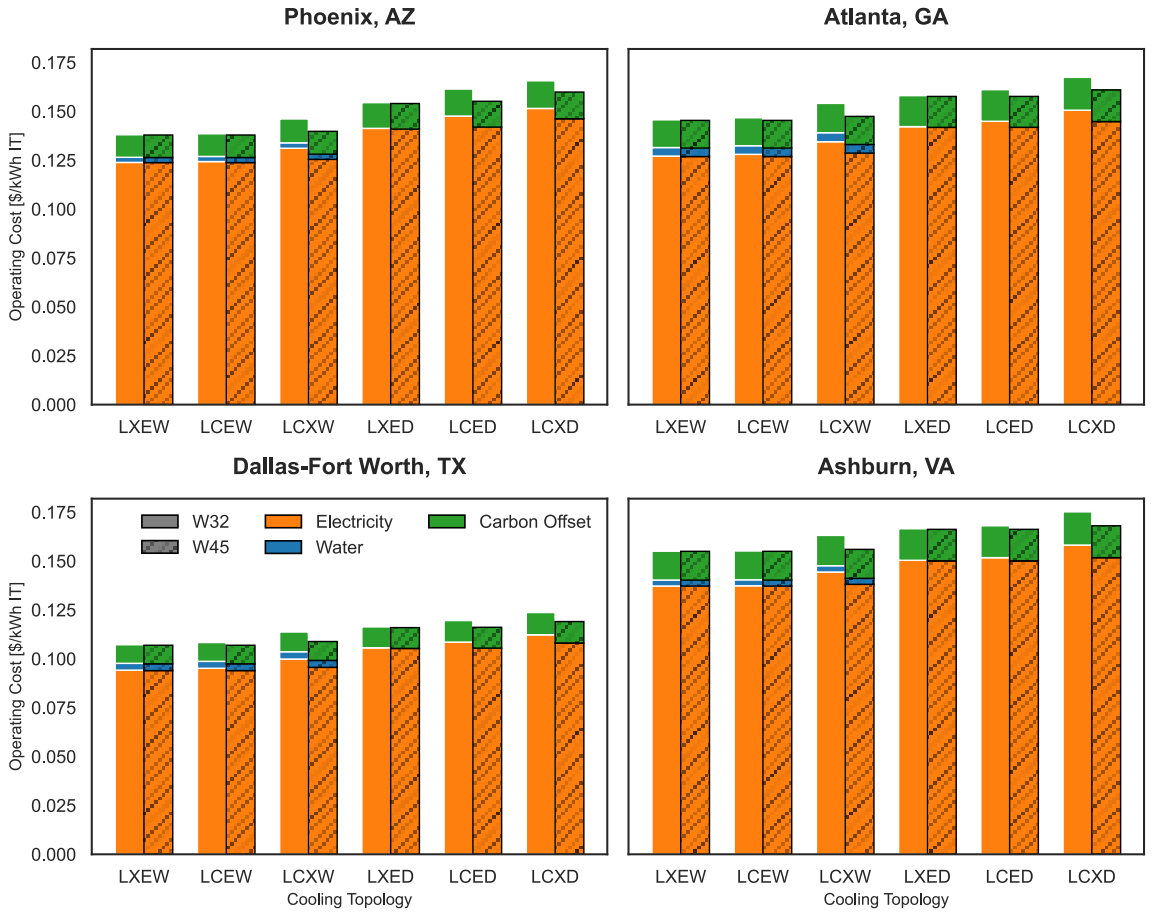
V. Ganesh, H. Li, M. L. Maloney, W. Zuo 2026. "The Energy-Water-Carbon Nexus of Liquid-Cooled Data Centers: A Comprehensive Evaluation of Different Cooling Topologies." (Under Review)

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Case Study: Top 4 Hubs in USA





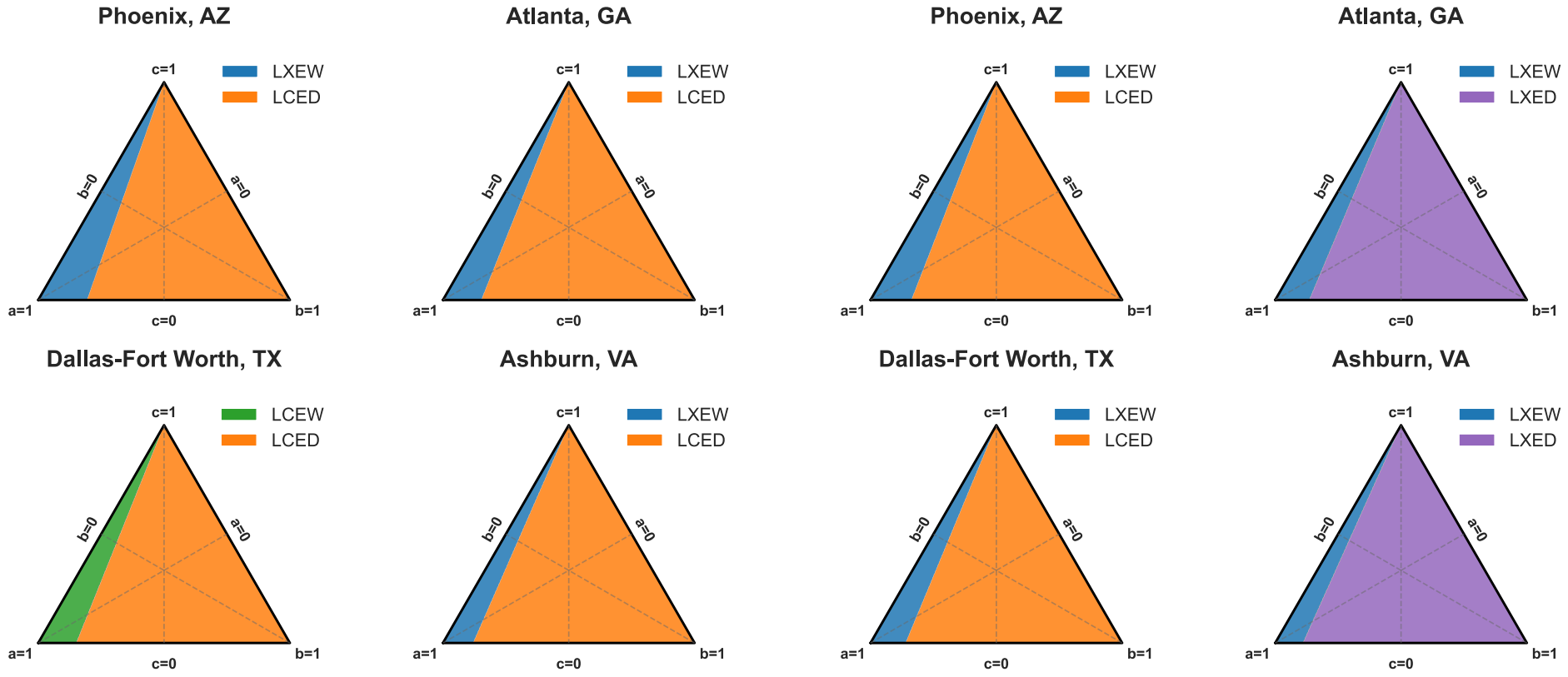
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Case Study: Top 4 Hubs in USA

$$RUE = \left(a \times \frac{1}{PUE}\right) + \left(b \times \frac{1}{1+WUE}\right) + \left(c \times \frac{1}{1+CUE}\right)$$

W32

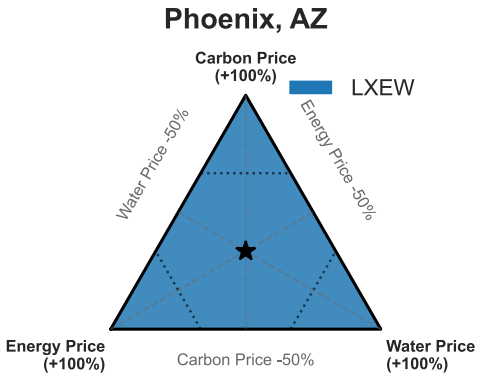
W45

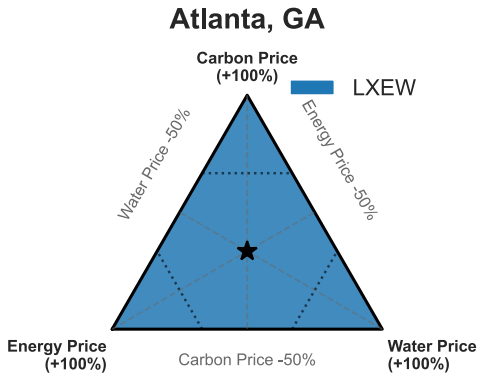


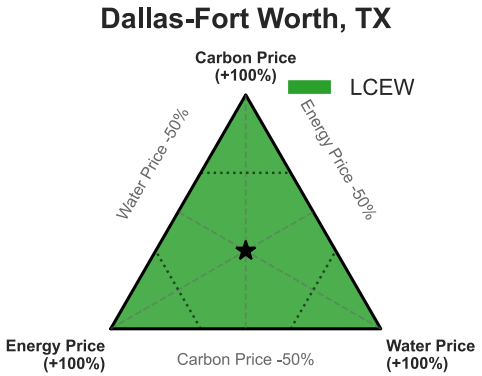
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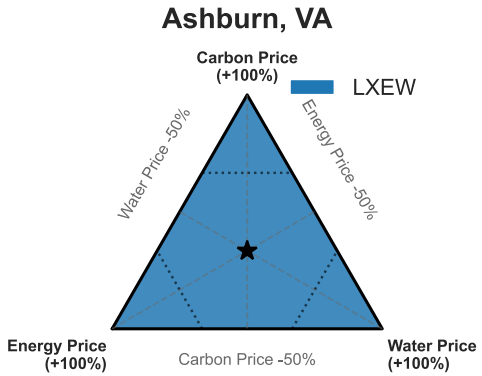
Case Study: Top 4 Hubs in USA

W32

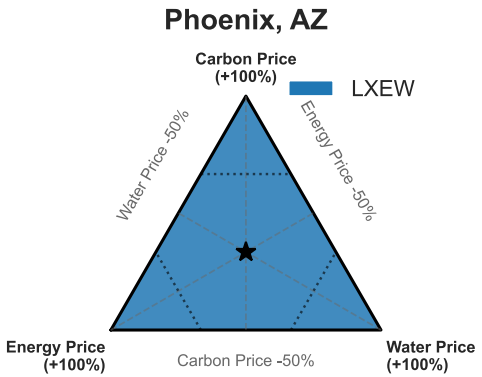


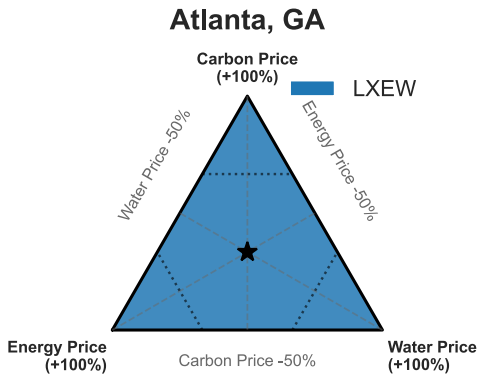


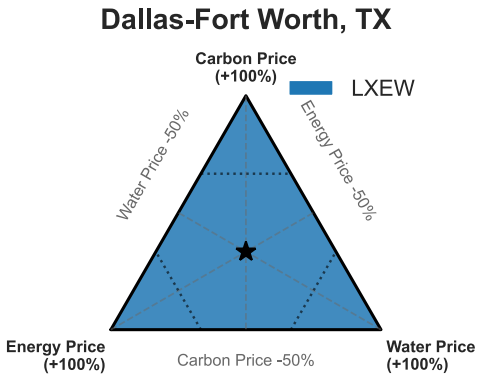


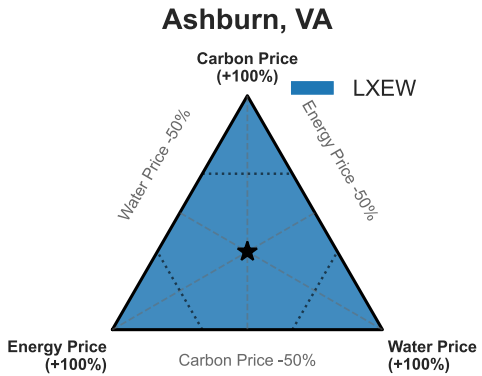


W45









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Outlook

- **Unified Modelica Test Bed introduced:** Enables rapid design and multi-metric evaluation of air and liquid data center cooling systems across energy, water, and reliability parameters.
- **Case Study (Miami, FL) (CZ 1A):** Demonstrated the framework's capability by directly comparing cooling system configurations in a hot and humid climate zone.
- **Case Study (Beyond PUE):** Highlighted the critical shift from a strict PUE (Power Usage Effectiveness) metric to a holistic, Nexus-based metric to optimize for local resource and regulatory constraints.

Acknowledgements



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Access to Model and Publications

Paper-1

V. Ganesh, H. Li, M. L. Maloney, W. Zuo 2026. "DCOPTEST: A Novel Unified Virtual Testbed for Data Center Cooling Systems."SoftwareX. 36. pp. 103073.

Preprint

V. Ganesh, H. Li, M. L. Maloney, W. Zuo 2026. "The Energy-Water-Carbon Nexus of Liquid-Cooled Data Centers: A Comprehensive Evaluation of Different Cooling Topologies."

DCOPTEST

GitHub Repository

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Thank you!

Viswanathan Ganesh

viswanathan.ganesh@psu.edu

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