2024 PROJECT PEER REVIEW

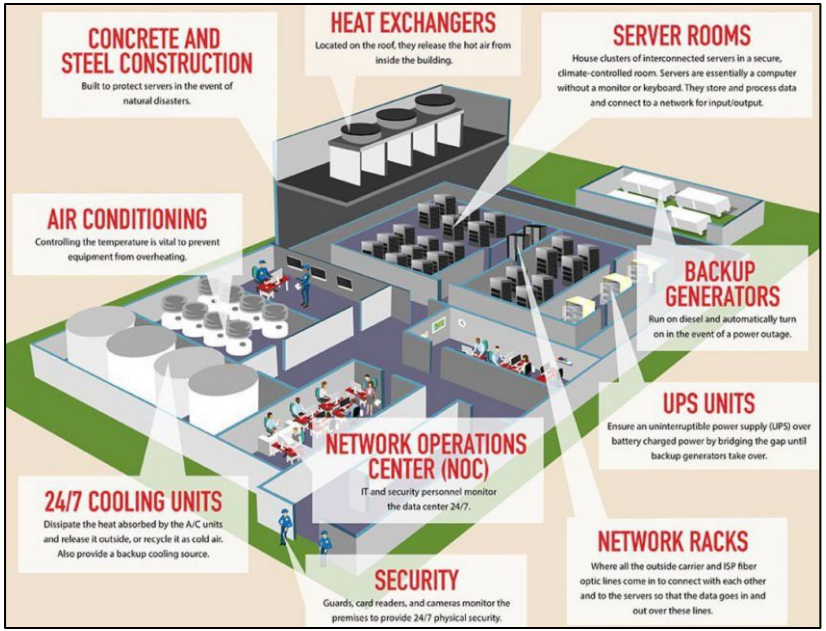
U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review:

Ultra-low Global-Warming-Potential Heat Transfer Fluids to Reduce Carbon Footprint in Data Centers



Ultra-low Global-Warming-Potential Heat Transfer Fluids to Reduce Carbon Footprint in Data Centers



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WBS: 03.02.02.38.NS05

Project Summary

OBJECTIVE, OUTCOME, AND IMPACT

Data centers represent at least 2% of US energy consumption and are growing significantly (2.5× in the next 5–6 years).

We are focused on reducing energy consumption using sustainable technologies: Two-phase immersion using ultra-low **G**lobal-**W**arming-**P**otential heat transfer fluids.

Reduce energy consumption by 40% using new technologies such as two-phase immersion.

DRIVERS

AI: artificial intelligence

Internet of Things (IoT): internet usage



TEAM AND PARTNERS

PI: Samuel F. Yana Motta

ORNL Researchers: Abraham Lee, Cheng-Min Yang, Junjie Luo

CRADA Partner: Chemours (Gustavo Pottker)

Industry Collaborators: LiquidStack (manufacturer of equipment for data centers), Boyd (enhanced surfaces)

STATS

Performance Period: FY24/FY25

DOE Budget: $300K, Cost Share: $300K

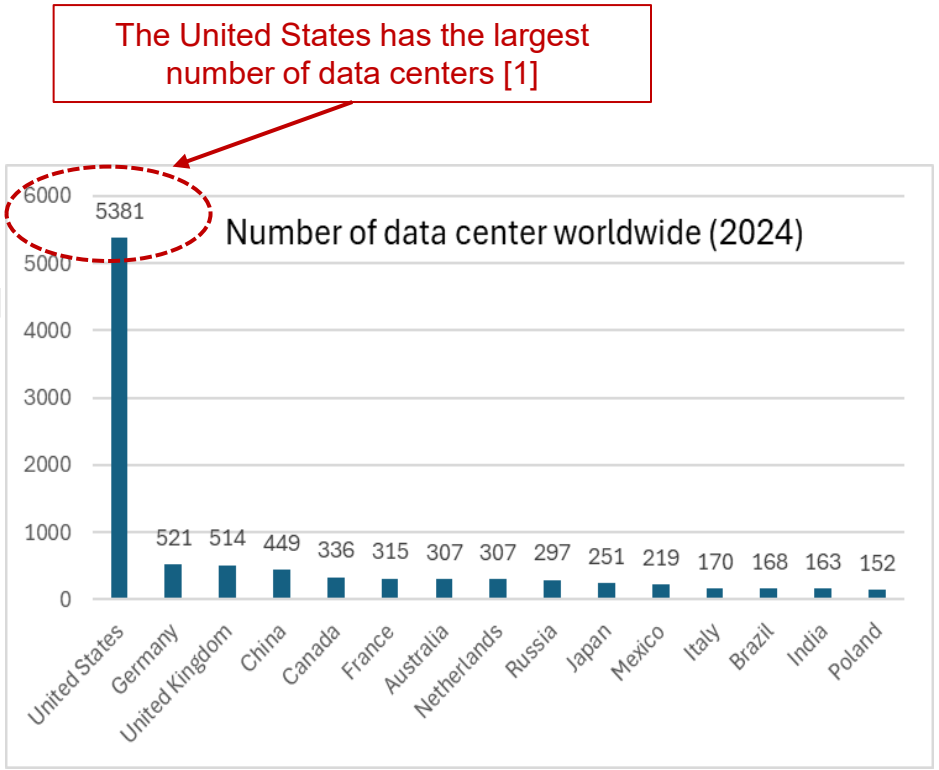
Milestone 1: Simulation of liquid tank

Milestone 2: Perform life cycle climate performance and explore other cooling technologies

Milestone 3: Enhanced surfaces heat transfer

Problem

- Data centers are buildings fully dedicated to hosting servers and their auxiliary systems (cooling equipment, controls, people managing the facility)
- Data centers represent 2% of annual US energy consumption [2] and are expected to grow at least 2.5× in the next 6 years
- Most data centers are air-cooled with a performance usage effectiveness (PUE) of 1.4 to 1.7
  - A PUE of 1.7 means that the cooling system is equivalent to 70% of the total IT load
  - Two-phase immersion using dielectric fluids can reduce PUE to 1.02 (40% less energy consumption)
- Air-cooled data centers can dissipate heat only up to 37 W/cm^2, but latest generation chips require up to 100 W/cm^2
  - Two-phase immersion can reliably provide these high dissipation rates



[1] https://www.statista.com/statistics/1228433/data-centers-worldwide-by-country
[2] de Bock, P., V. Lecoustre, C. Noyes, T. Bress, R. Radhakrishnan, and J. Gallagher. 2021. "Cooling Compute Systems Efficiently, Anytime, Anywhere." *Energy Efficiency Computing Workshop*, December 21, 2021 (https://www.arpa-e.energy.gov/sites/default/files/4.%20Vision%20Pitch%20-%20deBock.pdf)

Alignment

- Combining a **high-efficiency technology** (two-phase immersion) with **ultra-low GWP heat transfer fluids** drastically reduces GHG emissions.
- Reducing energy consumption indirectly helps to decarbonize the power system
- By lowering the energy usage of data centers (cost of operation), we will enable the deployment of AI and IoT to the general population



Greenhouse gas emissions reductions

50-52% reduction by 2030 vs. 2005 levels

Net-zero emissions economy by 2050



Power system decarbonization

100% carbon pollution-free electricity by 2035



Energy justice

40% of benefits from federal climate and clean energy investments flow to disadvantaged communities

Potential Impact: Initial Estimates for Two-phase immersion

	Typical Air- Cooled	Two-Phase Immersion (2P50)
PUE = Total Facility Power / IT Equipment Power	**1.70**	**1.03**
GWP of Heat Transfer fluid	0	~10
Indirect Emissions: **Total annual energy consumption per Data Center (GWh)**	54.9	32.9
Indirect Emissions: **Cooling annual energy consumption per Data Center (GWh)**	22.6	0.6
Indirect Emissions: **Annual emissions due to energy use (kt of CO_2)**	***23.1***	***13.8***
Direct Emissions: **Total amount of immersion cooling fluid per DC (t)**	0.0	55.3
Direct Emissions: **Annual amount of fluid leaks per Data Center (t)**	0.0	0.55
Direct Emissions: **Annual emissions due to leaks per Data Center (kt of CO_2)**	***0.0***	***0.005***
Annual Total emissions per Data Center (kt of CO_2) -	***23.1***	***13.8***
Percent change in CO_2 total annual emissions (%)	Baseline	**−40%**

[a] DC = data center

GHG emissions can be reduced drastically.

Approach Why evaluating new heat transfer fluids?

		Commercially Available Fluids			New Fluid
		FC-3284 / FC-72	**HFE 7100**	**Novec 649**	**2P50**
Thermal Properties	**Normal boiling point (°C)**	50/56	61	49	48.9
	Heat of vaporization at normal boiling point (kJ/kg)	100/88	118	88	108
	Estimated heat transfer coefficient (kW/m^{2}K)	10.6/10.0	11.6	10.3	10-12
Electric Properties	**Dielectric strength (kV, 0.1 in. gap)**	~40	~40	~40	41.3
	Volume resistivity (Ohm-cm)	1.0E+15	1.0E+8	1.0E+12	5.1E+14
	Dielectric constant	1.8	**7.4**	1.8	1.75
Environmental	**GWP – 100 years**	**>9,000**	297	1	10
Reliability	**Sensitivity to common contaminants**	Acceptable	Acceptable	**Not Acceptable**	**Acceptable**

FC-3284/FC-72 has very High GWP

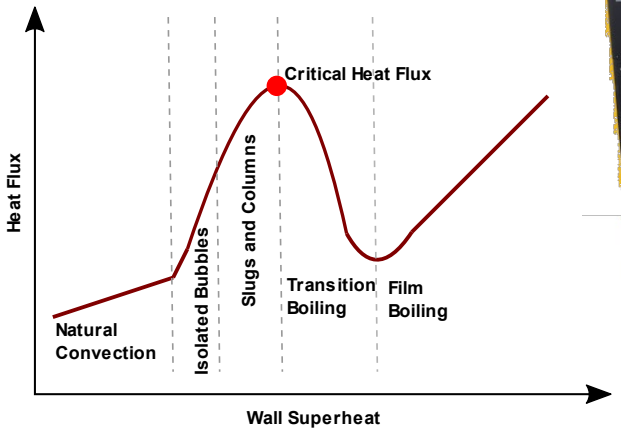
HFE 7100 has poor dielectric properties

Novec 649 shows high sensitivity to moisture, requiring very stringent contaminant controls

Approach How?

Step1

Characterization of the Fluid (Heat Transfer, Critical Heat Flux)



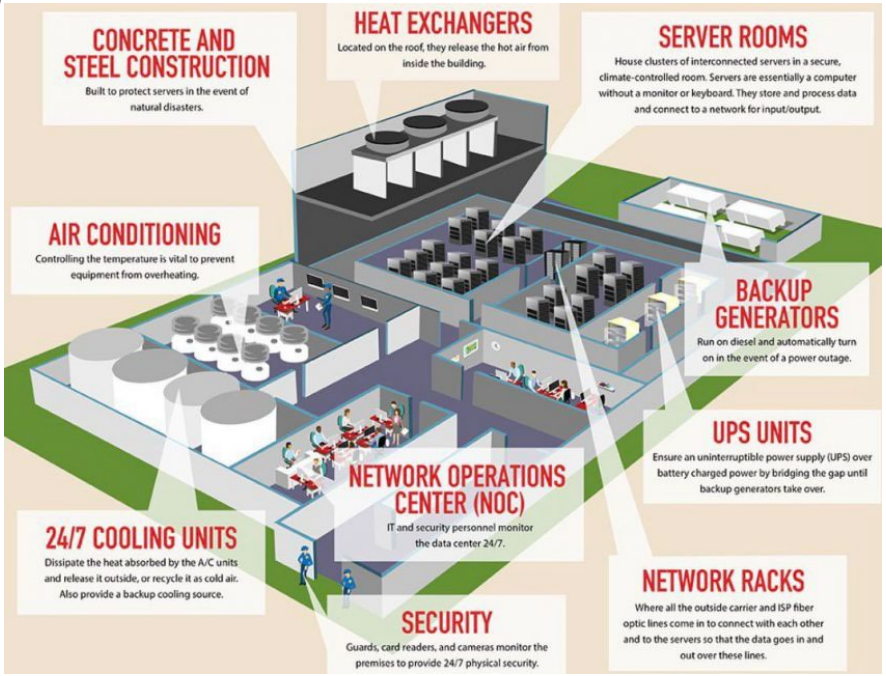
Step 2

Two-Phase Immersion (Equipment Performance)



Step 3

Energy Modeling and Simulation of Data Center Buildings



Approach Risks and Implementation Strategies

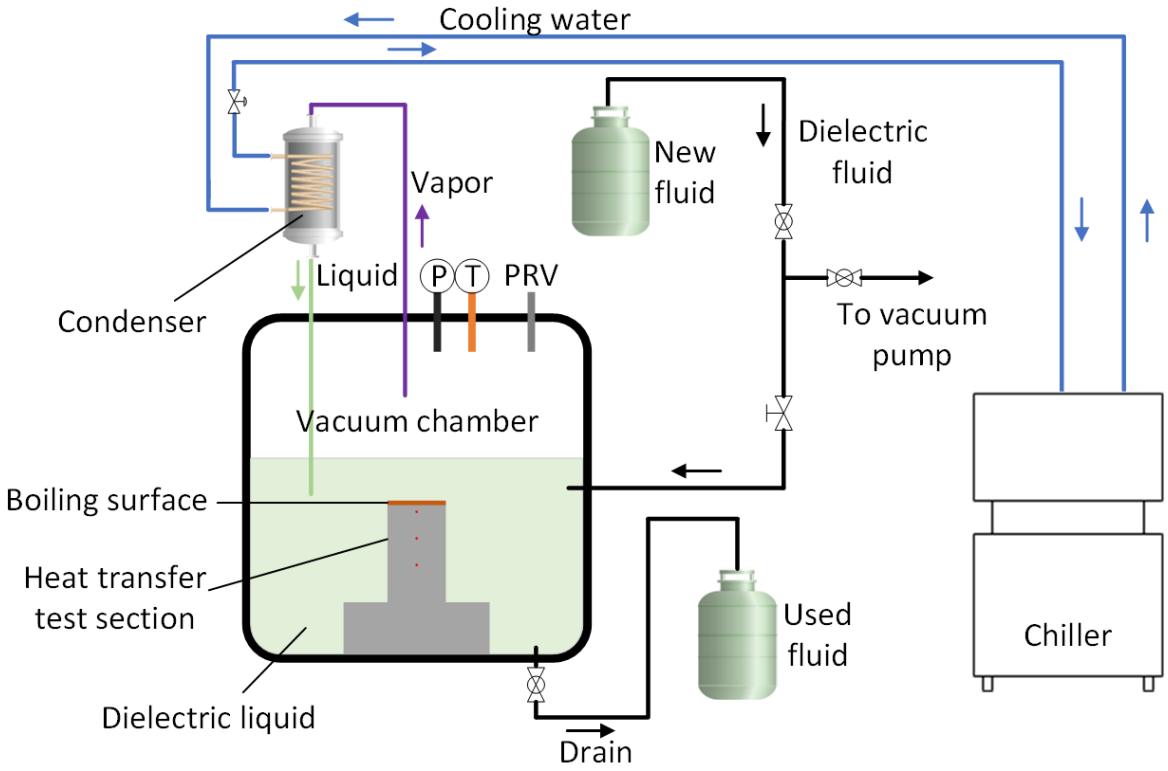
- **Barriers, technical challenges, risks**
  - Using two-phase immersion coupled with ultra low GWP fluids, we'll drastically reduce GHG emissions of current data centers.
  - Perform long duration server testing (at least 6 months) to validate the reliability of the equipment using the new heat transfer fluid.

- **Mitigation strategies for risks**
  - Investigate the design/operation of two-phase immersion equipment to achieve optimum efficiency (lowest possible PUE)

- **Demonstration strategy**
  - Collaborate with CRADA partner (Chemours) and equipment manufacturers (Liquistack, Boyd) in filed evaluations.

- **Commercialization strategy**
  - Collaborate with manufacturers to implement this new technology in actual applications. Disseminate results in conferences and industry magazines.

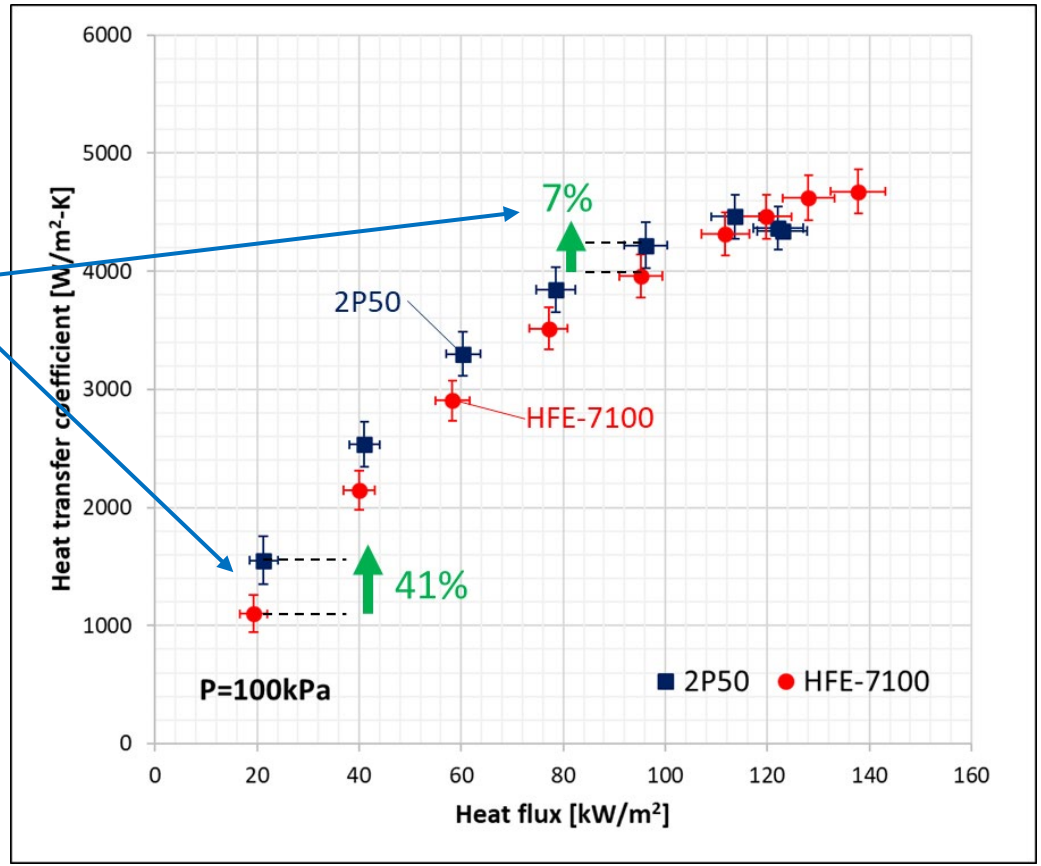
Progress Apparatus for Pool Boiling Heat Transfer



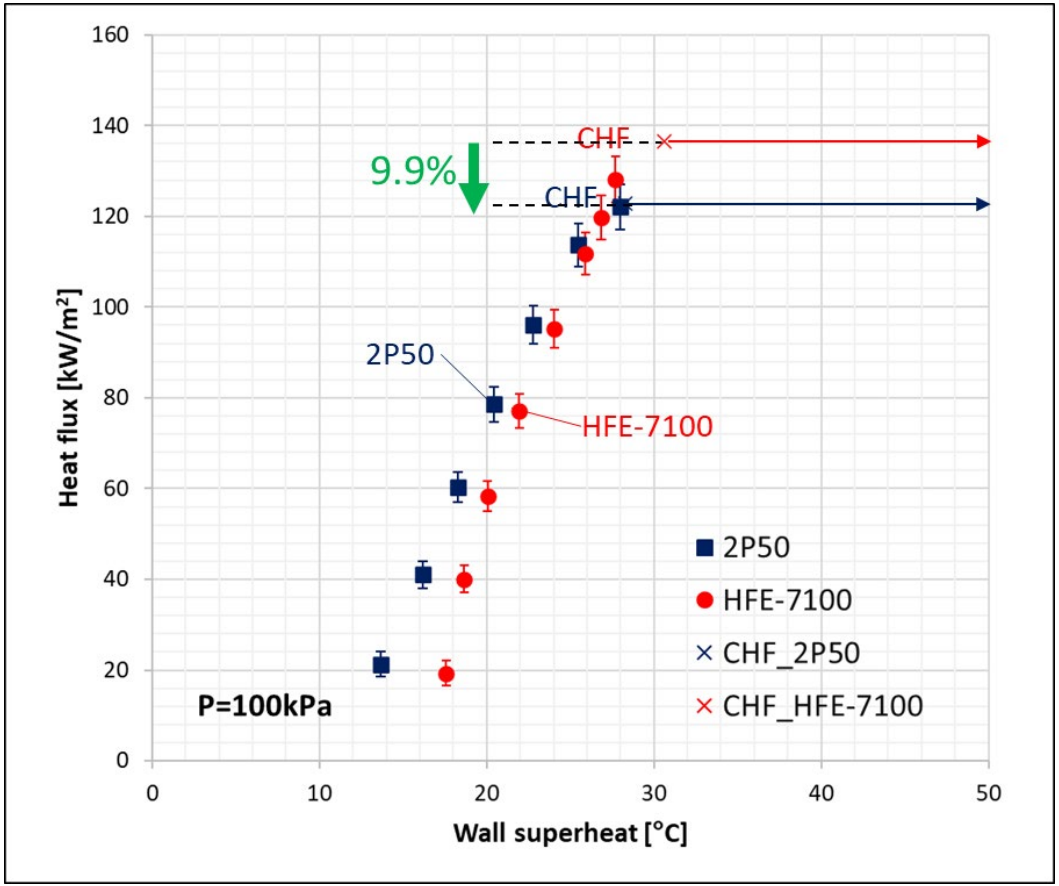
Progress Heat Transfer measurements for Smooth Surfaces

2P50 shows 7% to 41% higher heat transfer coefficient compared to a HFE-7100

We will verify these benefits when testing enhanced surfaces.



Progress Critical Heat Flux for Smooth surfaces



2P50 shows slightly lower Critical Heat Flux compared to HFE-7100

CHF can change significantly when using enhanced surfaces.

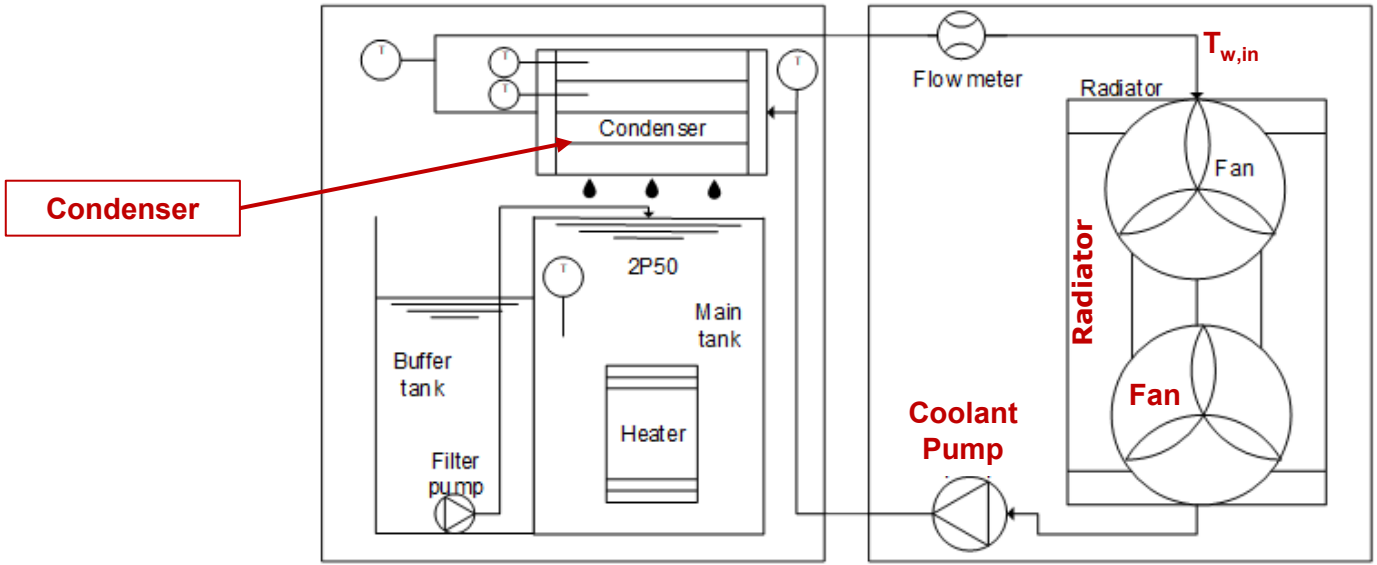
The testing of enhanced surfaces is next in the evaluation plan.

Critical heat flux (CHF):
Heat flux at which boiling ceases to be an effective form of transferring heat from a surface to a liquid.

Wall superheat:
Difference between the wall temperature and the saturation point of a fluid

Progress Equipment Testing

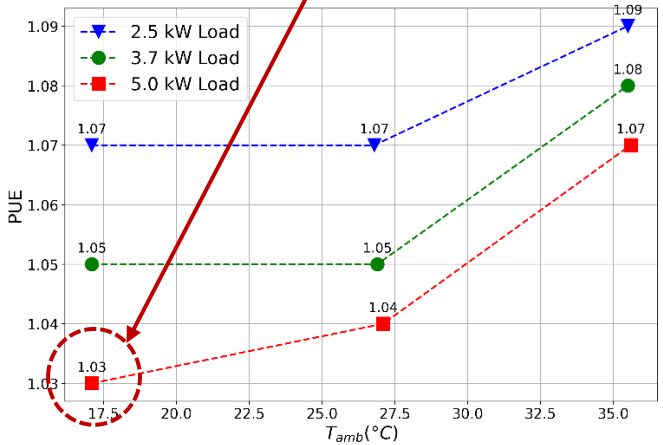
Ambient Temperature
(Use environmental chamber)

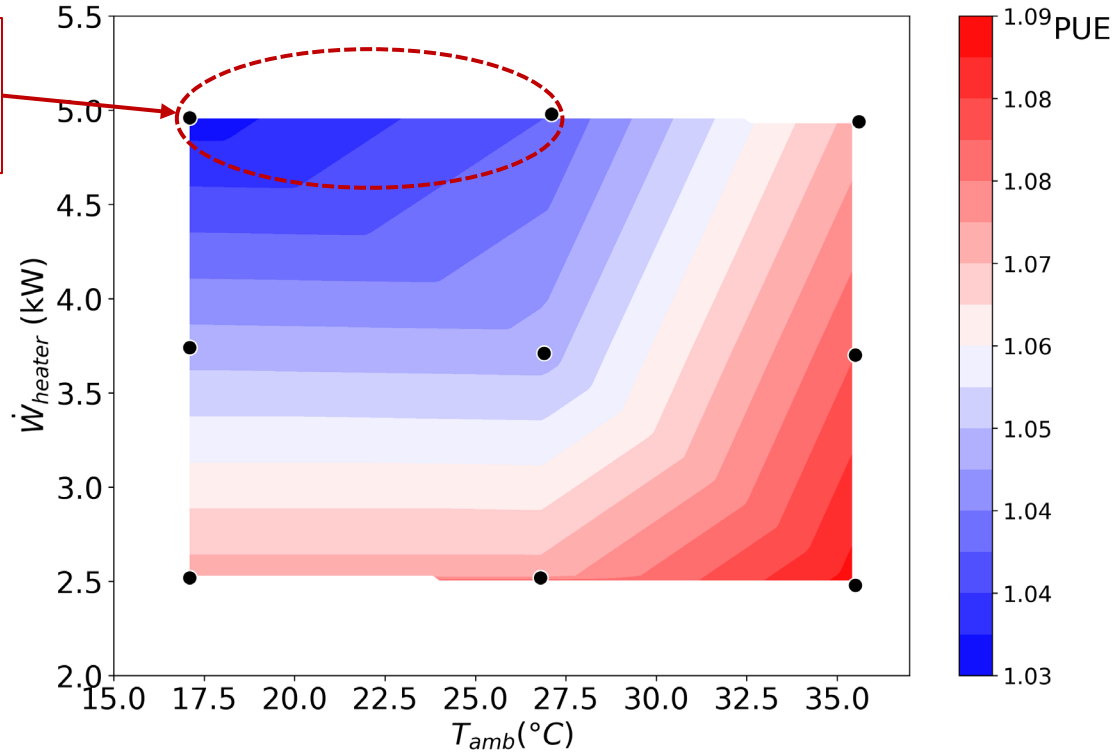


Test Matrix				
Ambient Temperature T_{amb} (°C)	**Information Technology Load (kW)**	**Coolant Inlet Temperature $T_{w,in}$ (°C)**	**Coolant Pump (speed Setting)**	**Radiator Fan (speed setting)**
17	2.5	32	Auto	Auto
27	3.7	35	Minimum	Minimum
35	5	38	Maximum	

Progress Results of Equipment Testing

PUE ranging from 1.03 to 1.04 were measured at moderate ambient conditions (27ºC and below).





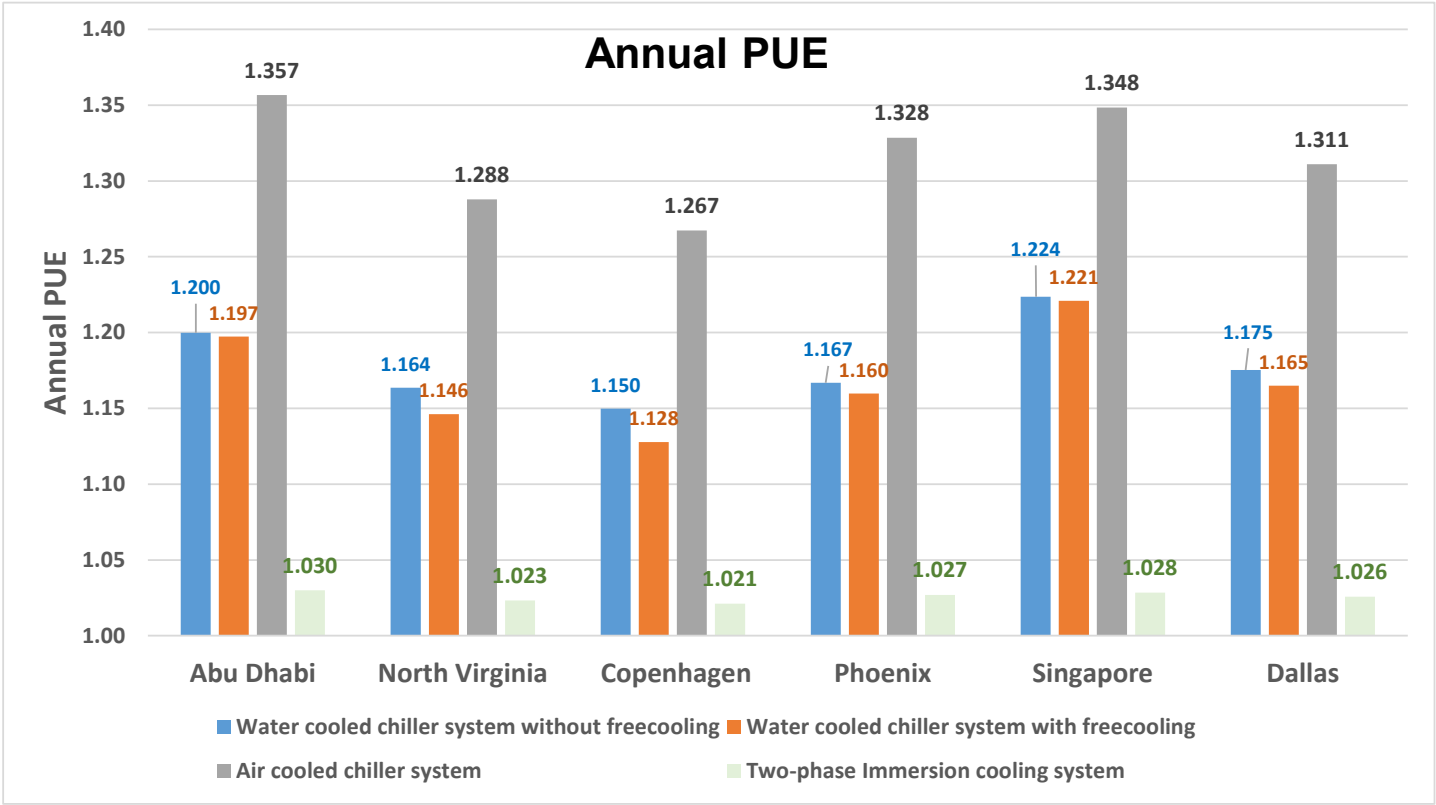
Good energy efficiency is attainable even for warm locations such as Florida.

Progress Power Usage Effectiveness (**PUE**) of a 50 MW Data Center

The annual operations of a 50 MW data center building were simulated using EnergyPlus.

Modern air-cooled systems were used to provide the fairest possible comparison.

Two-phase immersion showed an annual PUE values ranging from 1.021 to 1.03.



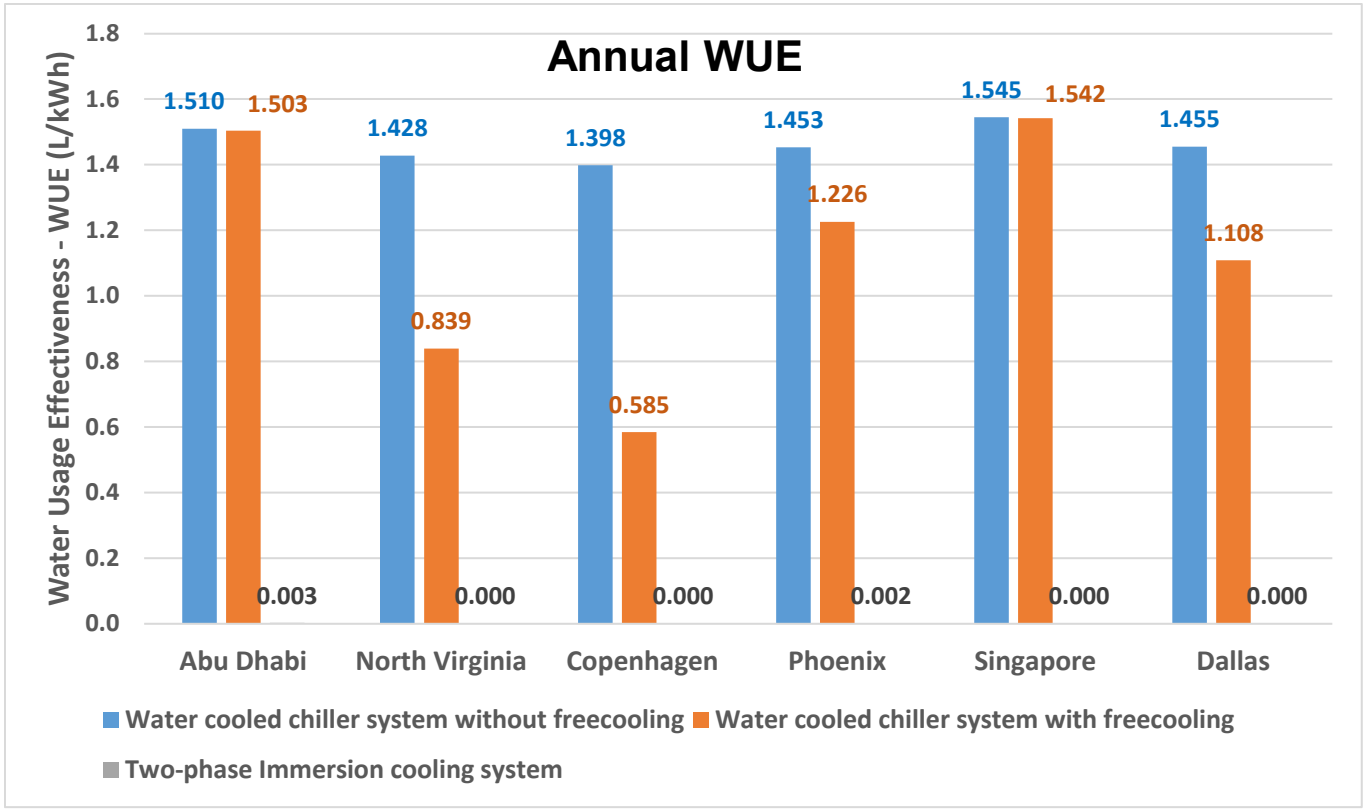
Progress Water Usage Effectiveness (**WUE**) for a 50 MW Data Center

The **W**ater **U**sage **E**ffectiveness (**WUE**) is the ratio between water usage and the IT energy consumption

WUE measures the sustainability of a data center.

Data centers using water-cooled chillers showed high water consumption (0.585 to 1.545)

Two-phase immersion technology showed negligible use of water (near zero values)



Future Work

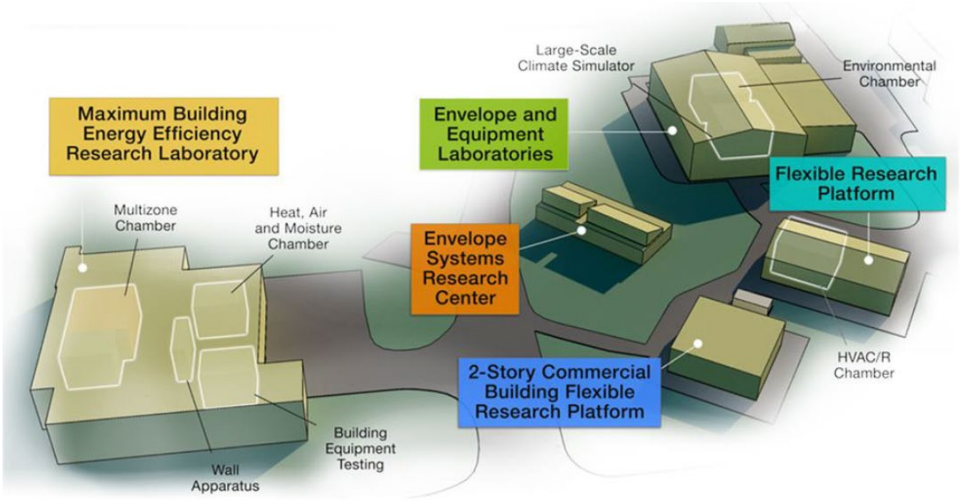
- **Completion of current project tasks:**
  - Evaluate heat transfer for enhanced surfaces used in data centers (use samples provided by manufacturers)
  - Simulation and optimization of liquid tank: modify components to obtain the lowest possible PUE (better efficiency)
  - Perform LCCP analysis for more locations in the United States and other regions and estimate impact on energy consumption
  - Assist our CRADA partner and other industry players to provide a sustainable solution for data center facilities (commercialization)
- **Explore other technologies:**
  - Waste heat recovery: extract energy using organic Rankine cycle.
  - Evaluate other cooling technologies for data centers.
  - Use combined with thermal energy storage.

Thank you

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WBS 03.02.02.38.NS05



The **Building Technologies Research and Integration Center (BTRIC)** at ORNL has supported DOE BTO since 1993. BTRIC is comprised of more than 60,000 square feet of lab facilities conducting RD&D to develop affordable, efficient, and resilient buildings while reducing their greenhouse gas emissions 65% by 2035 and 90% by 2050.

Scientific and Economic Results
139 publications in FY24
140+ industry partners
60+ university partners
16 R&D 100 awards
64 active CRADAs

BTRIC is a DOE-Designated National User Facility

Reference Slides

Project Execution

	FY2024				FY2025				FY2026			
Planned budget	$300K				$300K							
Spent budget	$200K											
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Critical literature review												
Whole building energy modeling												
Testing of equipment												
Current/Future Work												
Simulation of liquid tank												
Life cycle analysis (LCCP) – Explore other technologies												
Enhanced surfaces heat transfer												

Team



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