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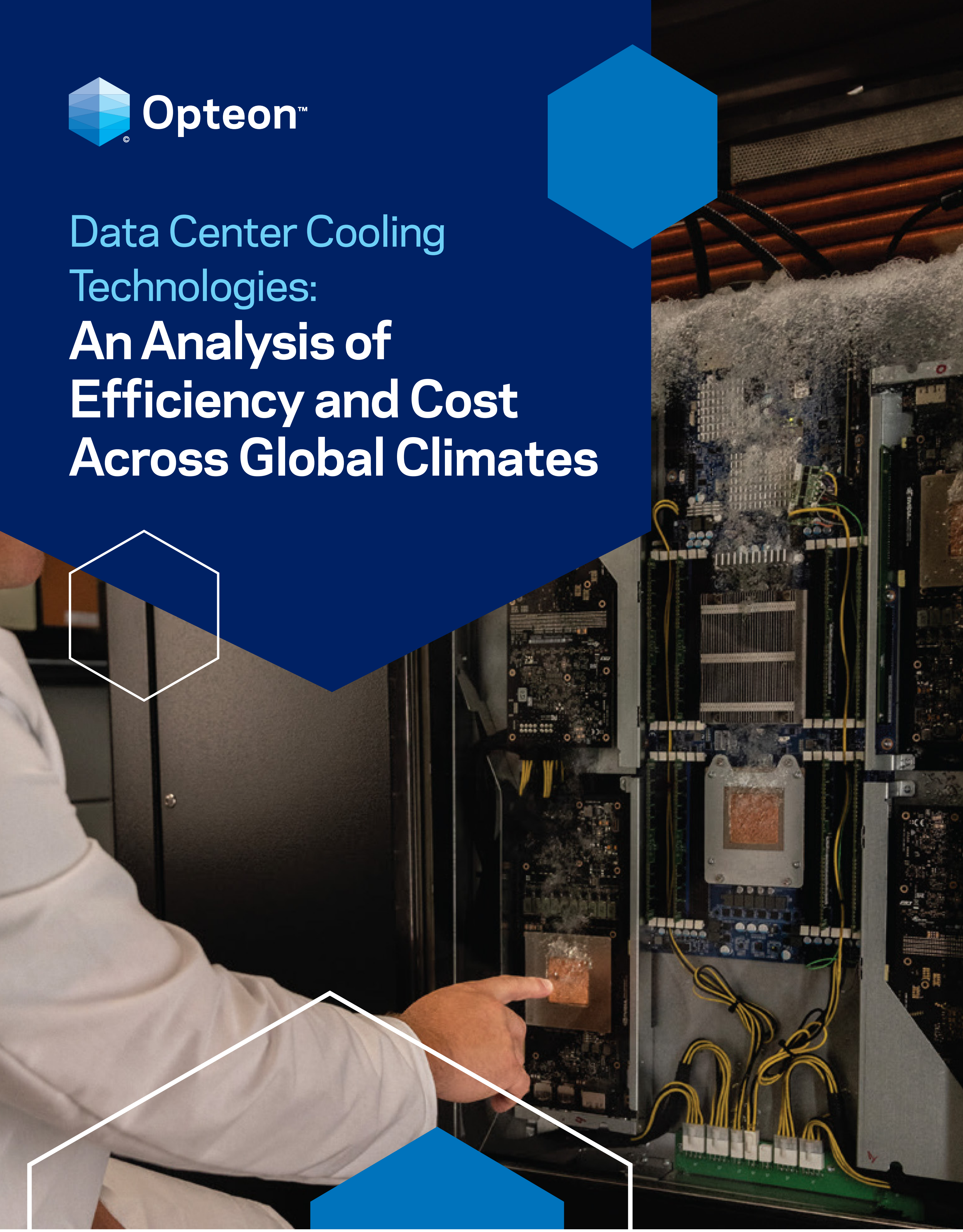
Data Center Cooling Technologies:
An Analysis of Efficiency and Cost Across Global Climates



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Navigating Modern Data Center Challenges

In today's technology-driven world, the data center industry plays a crucial role. Still, it faces ever-increasing challenges due to heightened demands from artificial intelligence and other high-powered computer applications. These challenges revolve around critical resources such as energy, water, and physical space, that have driven increases in energy, land, and water consumption. Another challenge facing the industry is how to cool next-generation processing units effectively.

Leading developers in the liquid cooling sector have produced advanced solutions that have been rigorously analyzed to mitigate environmental impacts while optimizing cost, efficiency, and long-term enablement of next-generation components. These solutions are the way forward and address the challenges The industry is facing.

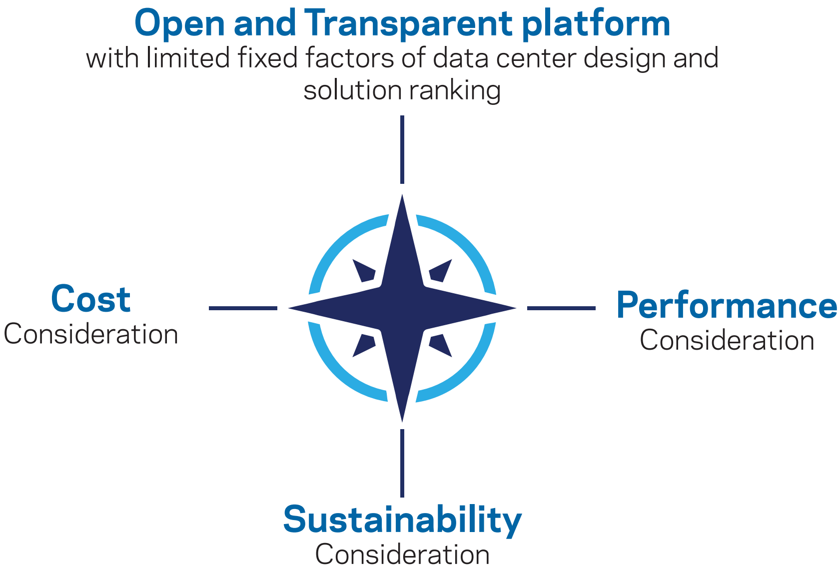
Liquidstack and Chemours commissioned a study from Syska Hennessy Group[1] to support the industry in answering a critical question: what next-generation liquid cooling solution is right for future data centers?

Leveraging Syska Hennessy's extensive expertise in data center design, the project gave rise to an innovative Total Cost of Ownership (TCO) tool. This tool helps evaluate the financial impacts of using different cooling technologies, such as Single-Phase Direct-to-Chip, Single-Phase Immersion Cooling, and Two-Phase Immersion Cooling, in various data center locations worldwide, including Copenhagen, Ashburn (Virginia), Singapore, and Abu Dhabi.

Key Terms and Abbreviations

1-PIC – Single-Phase Immersion Cooling
2-PIC – Two-Phase Immersion Cooling
AI – Artificial Intelligence
CAPEX – Capital Expenditure
CDUs - Cooling Distribution Units
CPU – Central Processing Unit
CRAH - Computer Room Air Handler
DTC - Direct-to-Chip
GPU - Graphics Processing Unit
HPC - High-Performance Computing
OPEX – Operational Expenditure
PUE - Power Usage Effectiveness
TCO - Total Cost of Ownership
TDP - Thermal Design Power
UPS - Uninterruptible Power Supplies
WUE - Water Usage Effectiveness

A Transparent TCO Model for Sustainable Data Center Cooling



Driven by the escalating heat demands from GPUs and CPUs used in AI, HPC, and cryptocurrency mining, the TCO model was developed to offer a transparent tool for evaluating the total cost and sustainability of various data center cooling technologies. The model addresses the financial implications of adopting advanced cooling methods like Direct-to-Chip, Single-Phase, and Two-Phase Immersion Cooling, which are necessary to handle GPU TDPs exceeding 1000W and higher rack densities.

By incorporating climate data and specific design conditions, the TCO model enables a practical comparison of different liquid cooling technologies in terms of resource use and operational costs. This allows data centers to make informed decisions that meet their future demands efficiently and sustainably, regardless of their global location.

Key Features of the TCO Model

1. **Transparency:** All inputs are viewable and selected from high-quality, publicly available sources.

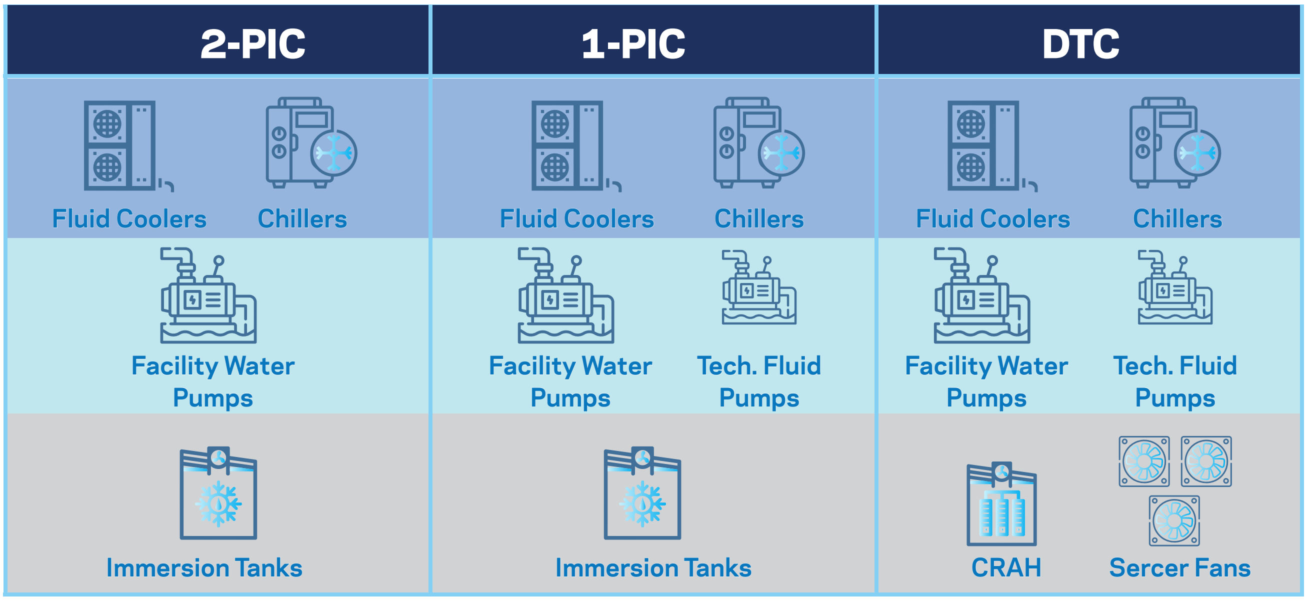
2. **CAPEX:** Includes costs related to electrical infrastructure (transformers, generators, UPS), mechanical infrastructure (chillers, CDUs, pumps), server modifications, and architectural costs.

3. **OPEX:** Considers electricity costs (IT, chillers, CDUs, tanks), water/propylene glycol loops, IT distribution losses, CRAH, server fans, water usage, sewer expenses, and maintenance costs.

4. **Technical Data:** Utilizes publicly available equipment information and specific design location weather data and leverages well-known design standards.

The TCO model aims to empower the industry to ascertain the best solutions for their data centers by providing a comprehensive framework for evaluating total cost and sustainability metrics, ultimately contributing to a more efficient and environmentally responsible data center ecosystem.

Model Calculation Methods - Energy and Water Consumption



Method/ Source

- **Actual manufacturer performance** “kW/Ton” curves based on outside dry-bulb, wet-bulb and required facility temps.
- This is for chillers. All other equipment data was provided by Liquidstack or from publicly available data sheets from leading manufacturers.
- **Hourly kWh** calculation and interpolation for the entire year
- Dry-bulb depression for **adiabatic coolers**
- Total **pressure drop** calculated for facility water and technology loops, including **cold-plate, tank, CDU, piping losses**
- **Flow rates** obtained based on specific **ΔTs** Across tank, cold-plate and IT capacity
- Pump and **motor efficiencies** factored in
- Tank power data from **manufacturers**
- **Server fan** power based on required air flow rates and available performance data
- **CRAH power** estimated based on available performance data

Total kWh was obtained by adding all energy-consuming components for each hour of the year. Review the full case study for more details on data sources and extrapolation.

Floor space utilization is another critical aspect that this model considers. It accounts for the data hall, tanks, or racks, CRAH units, necessary clearances, and spaces for electrical rooms and heat rejection components like chillers, fluid coolers, transformers, and generators. This comprehensive approach ensures a detailed analysis of the costs associated with deploying and operating various data center

Highlights and Findings: Efficiency and Climate Adaptability of Data Center Cooling Technologies

Cooling Efficiency

2-PIC emerged as the superior technology in terms of efficiency, displaying a lower Power Usage Effectiveness (PUE) and Water Usage Effectiveness (WUE) across all climates. Its potential ability to operate effectively without chillers in cooler climates like Copenhagen and with minimal water use in warmer climates highlights its adaptability and high energy efficiency even in the most challenging of climates.

Climate Zone Impact

The study clearly demonstrated that the effectiveness of cooling technologies varies significantly with the climate characteristics of each location. Technologies like 2-PIC that can adapt to different ambient conditions without the need for extensive mechanical cooling have a distinct advantage.

Future Technology Scalability

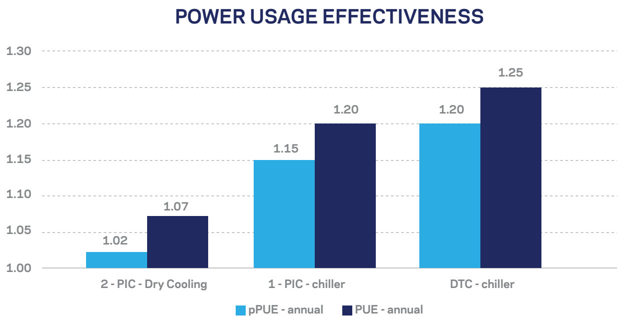
Considering future advancements in IT loads, 2-PIC can maintain its performance without substantial increases in CAPEX, continuing to offer a lower TCO and better resource utilization in all cases.

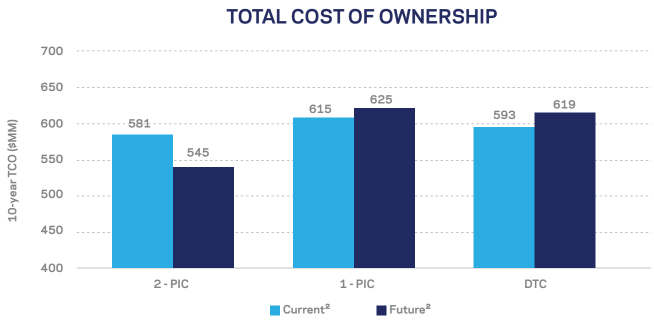
Space and Cost Implications

While DTC generally has similar space requirements due to its compact design, 2-PIC can deliver lower OPEX and up to 40% lower TCO in certain climates and presents the most cost-effective solution over a 10-year period due to lower operational costs and competitive capital expenses across all evaluated locations. The elimination of certain mechanical systems, such as forced air systems, supports the reduced CAPEX.

Learnings Using the TCO Model

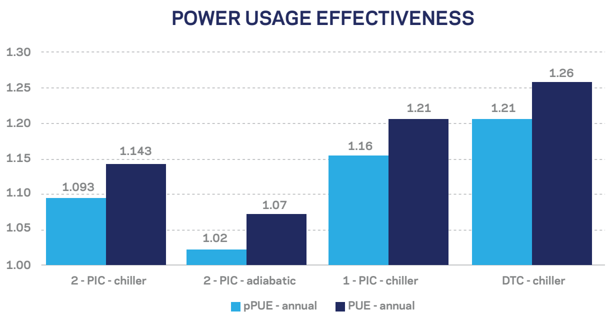
Copenhagen, Denmark – Mild Climate

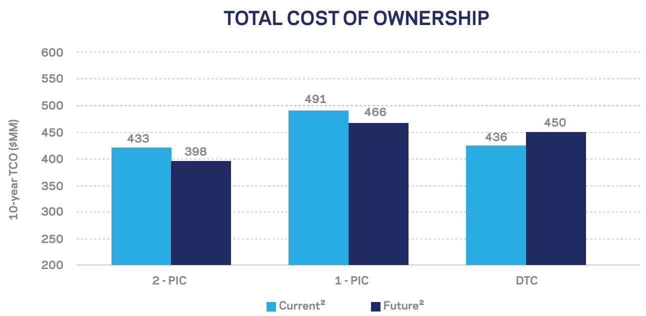




In Copenhagen, even under the requirement of future IT demands, Two-Phase Immersion Cooling (2-PIC) excels with minimal changes in Power Usage Effectiveness (PUE), remaining the most energy-efficient option. 2-PIC is the only option that can be designed to operate with dry cooling only, without chillers. In terms of operating costs, the full study[1] shows us how 2-PIC's operational costs remain stable, highlighting its sustainability and efficiency in cooler climates. Reduced building area for all technologies suggests improved space utilization, yet 2-PIC offers the lowest CAPEX, reinforcing its economic advantage.

Ashburn, Virginia – Warm Climate

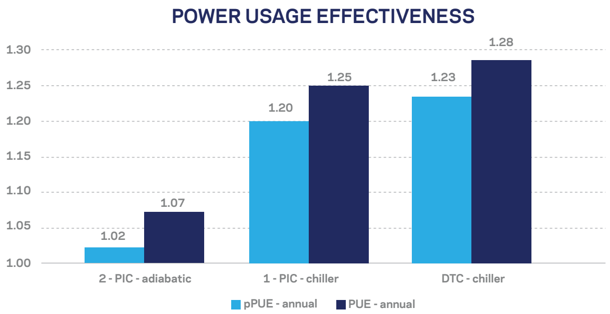


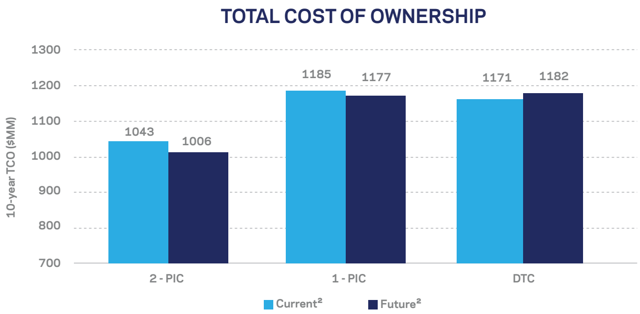


Ashburn highlights 2-PIC's capability to maintain lower energy use and PUE in varied climates, even as IT demands escalate. With an adiabatic cooler or chiller, 2-PIC still yields the lowest PUE, the lowest CAPEX, and OPEX among the three cooling technologies. With the chiller option, 2-PIC can also use the least space, slightly lower than DTC. With that, 2-PIC still retains the best Total Cost of Ownership (TCO) profile among the options. The notable increase in DTC's operational costs underlines the importance of selecting more energy-efficient cooling solutions like 2-PIC for long-term sustainability.

Singapore - Humid Climate

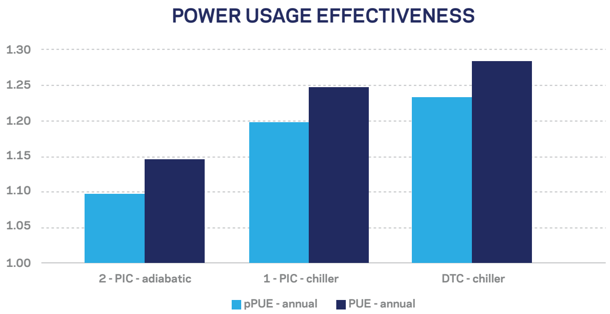
Even in a humid climate, 2-PIC still provides the best cost and energy efficiency performance. This region's high electricity costs amplify the importance of 2-PIC's high energy efficiency (low PUE), as evidenced by its significant cost savings over DTC and 1-PIC in both construction and operational expenses. Singapore demonstrates the critical economic and environmental benefits of adopting 2-PIC in hot, humid climates.

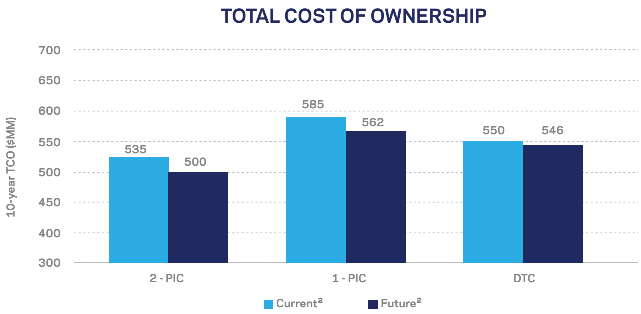




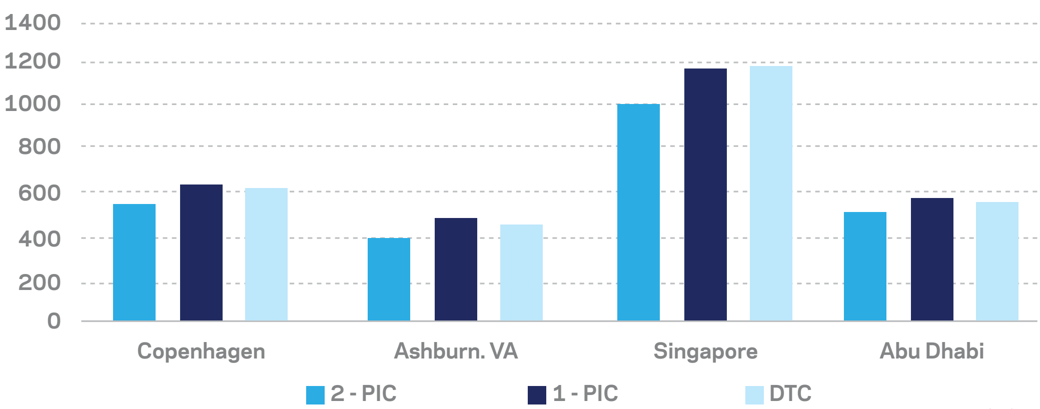
Abu Dhabi – Hot Climate

Abu Dhabi sees all technologies requiring chillers due to the hot climate. Here, 2-PIC adapts well, offering lower increases in energy consumption and maintaining the smallest yard size, which is crucial in densely built environments. Despite all technologies seeing an increase in construction costs, 2-PIC's superior energy efficiency and lower operational costs ensure it remains the most cost-effective solution when considering the total cost of ownership.





Summary Findings –   10 Year ($M/USD)



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Liquid cooling technologies demonstrate significant competitiveness, particularly when compared to air cooling options in the market today.

2-PIC consistently delivers the lowest TCO across all evaluated locations, standing out as the most cost-effective option.

The density of racks and tanks is contingent on server availability, which influences TCO calculations. As rack or tank density and TDP increase, further disparities in TCO among different liquid cooling technologies are anticipated.

Moreover, the cost of energy plays a crucial role in shaping OPEX and consequently, the overall TCO, highlighting the importance of energy efficiency in cooling solutions.

The data center industry is facing a crucial moment due to the increasing demands from the advancements in artificial intelligence, High-powered computing, and crypto mining. These growing demands continue to strain resources globally driving the absolute need for sustainable and scalable cooling solutions. According to the study across various global climates, Two-Phase Immersion Cooling is the optimal solution. It offers the lowest Power Usage Effectiveness and Water Usage Effectiveness, along with significantly reduced Operational Expenditures. It operates effectively without chillers in cooler climates and with minimal water in warmer regions, thus enhancing its sustainability.

Looking ahead, Two-Phase Immersion Cooling's long-term benefits, such as its ability to support higher rack densities without significant capital expenditure, position it as a foundational technology for future high-density data centers.

It is not only economically sustainable but also environmentally sustainable, making it an essential technology for data centers aiming to current and near-future high-density computing demands.

Explore Solutions for Your Operation

For businesses looking to enhance their data center operations through innovative cooling solutions, engaging with our team will provide access to leading expertise and technology. Contact us to explore how our findings can be applied to optimize your data center's performance and sustainability.

For further details, contact our collaborative team.

By choosing our advanced cooling solutions, you ensure your data centers are not only equipped to handle the demands of modern computing but are also aligned with sustainability goals, paving the way for a greener, more efficient future in data center technology.

References

[1] Comparison of Server Liquid-Cooling Technologies, Syska Hennessey Group Inc., Version 2, July 2024 with feedback provided by industry.

[2]

IT Load Scenarios	Current	Future
2-PIC Max IT Capacity per Tank	150.0 kW	250.0 kW
1-PIC Max IT Capacity per Tank	75,0 kW	110,0 kW
1-PIC CDU Max IT Capacity	500,0 kW	1000,0 kW
DTC Cabinet Max IT Capacity	75,0 kW	125,0 kW
DTC CDU Max IT Capacity	500,0 kW	1000,0 kW

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