Indirect Evaporative Cooling Drives Data Center Efficiency

Kao Data maintains the internal environmental conditions to ASHRAE's most stringent Class A1 Recommended Environment, without the use of any mechanical refrigeration.

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A data center is a building used to house and reliably support compute, storage, and networking equipment, termed by ASHRAE Technical Committee 9.9 (TC 9.9) as information technology equipment (ITE). The reliable and energy-efficient operation of the ITE equipment is crucial for business continuity, with design strategies devised to deliver continuous availability with zero downtime. The engineering architectures include various levels of redundancy, concurrent maintainability, and backup components across the entire building infrastructure, including power, cooling, telecommunications, security, environmental controls, and power monitoring.

The explosive growth of data is changing the world and, as such, the data center industry is driven by the continuing prodigious consumer demand for data. Greater volumes of data and content, transmitted and received faster, while being stored indefinitely, are facilitated by the technological advancements in the compute, storage, and networking required to meet the demand.

Data centers consume a tremendous amount of energy; therefore, a primary consideration for the design team was to ensure that the facility was as energy efficient as possible, especially as the power density of electronic equipment has been steadily increasing. In addition, the mission-critical nature of computing has sensitized businesses to the health of their data centers. The industry recognized that better alignment was needed between equipment manufacturers and facility operations personnel to ensure proper and fault-tolerant operation within mission critical environments. In order to address the above, ASHRAE TC 9.9 was created and, subsequently, the ASHRAE TC 9.9 guidelines were published (*Figure 1*).

The ASHRAE thermal guidelines are driving data-center performance and innovation, in which there are a variety of classes to adhere to that are dependent on the specific purpose of the data center and its associated operating requirements.

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Kao Data Campus

Kao Data Campus is a data center campus delivering +35 MW of technical space across four data center buildings. The first building, Kao Data London One, was built in 2017

Building at a Glance

Kao Data Campus

Location: London

Owner: Kao Data

Principal Use: Wholesale co-location data center, technology suites housing IT equipment

Gross Square Feet: 29,924

Technical Area Square Feet: 146,404

and has been operational since January 2018. Notably, Kao Data maintains the internal environmental conditions to ASHRAE's most stringent Class A1 Recommended Environment, without the use of any mechanical refrigeration. This is unprecedented for a wholesale co-location data center in the UK.

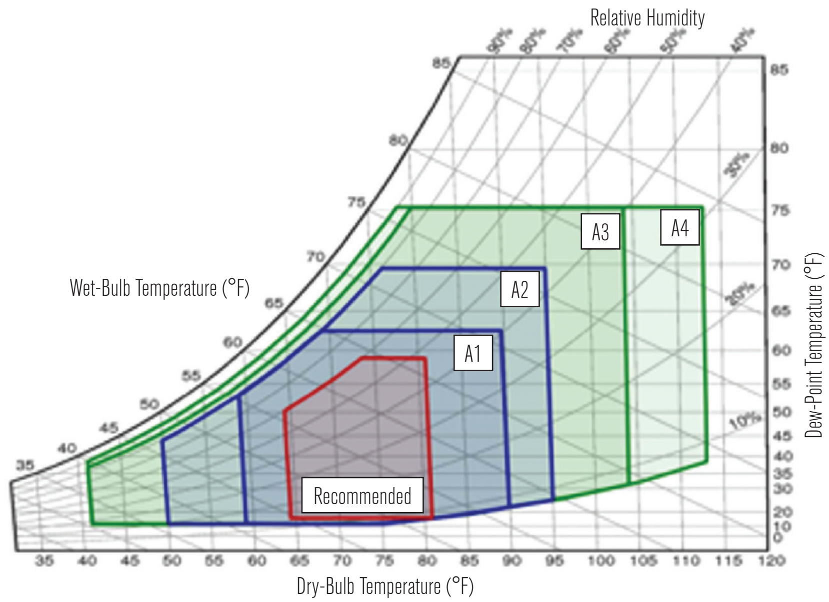


FIGURE 1 ASHRAE TC 9.9, thermal guidelines (2011).

Energy Efficiency

The primary cooling system at Kao Data incorporates indirect evaporative cooling (IEC) technology to maximize energy efficiency, while reducing the environmental impact. This is achieved through eliminating mechanical refrigeration, while maintaining internal conditions to the ASHRAE-recommended range of Class A1,[1] against the ASHRAE extreme maximum weather data and the full ITE load.

The IEC technology is comprised of modular air-handling units, each with an epoxy-coated aluminium air-to-air heat exchanger to optimize the approach temperature between external and internal air temperatures. The key functionality of the IEC technology utilizes adiabatic cooling via integrated water spray bars, under extreme external ambient conditions.

Additionally, environmental pressure and temperature differential feedback is continuously received from the technical space, and a control algorithm then determines the rotational speed of the internal and external electronically commutated (EC) fan walls circulating air to and from the space and across the heat exchanger before heat is rejected to atmosphere.

$$\text{Power Usage Effectivness} = \frac{\text{Total Facility Power}}{\text{IT Equipment Power}}$$

The Green Grid's power usage effectiveness (PUE) metric is the industry-recognized metric for assessing infrastructure effectiveness for data centers, whereby the total energy usage of the data center is divided by the energy usage of the IT equipment housed within the data center.

PHOTO 1 Architectural image of completed Kao Data Campus.

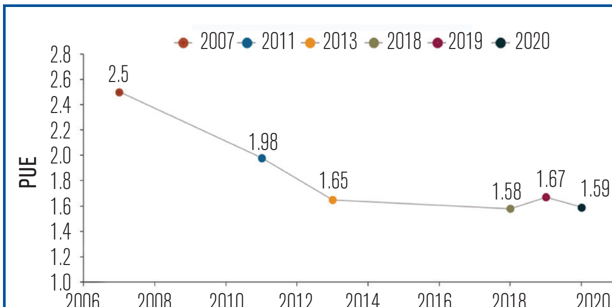


FIGURE 2 Data center efficiency gains have stalled. Source: Reported data center PUE figures in global Uptime Institute survey from 2007 to 2020.

Research conducted by the Uptime Institute shows that the average PUE for a typical data center has been falling over time, with the average PUE being 1.58 in 2018 (*Figure 2*). Typically, in an operational scenario, as IT equipment kW loads reduce from the maximum design load, the PUE goes up. This is predominantly due to lower efficiencies under part-load operation of the mechanical cooling systems and associated compressor performance plus the electrical systems' inefficiencies. However, through ingenuity, the team has managed to reverse the outcomes at the Kao Data Campus. Through the application of the Thermal Guidelines and elimination of mechanical refrigeration, the PUE evidenced during the commissioning and final integrated system test (IST) remained equal to, or below, the full-load PUE. As the ITE load reduced the cooling, the system dynamically responded with the facility input power tracking closer to the ITE input power, resulting in an optimized PUE and greater overall energy efficiency. The system underwent testing through commissioning levels 1–5, in accordance with ASHRAE Guideline 1.6P, *Commissioning of Data Centers*. The data collected during the various stages of testing, under full- and part-load conditions, enabled the theoretical design PUE modeling to be verified and recorded (*Table 1*).

Table 1 Validated PUE through integrated system testing (2.2 MW).

Simulated Thermal IT Load	Measured PUE
100% (2,200 kW [7.51 MBtu/h])	1.21
75% (1,650 kW [5.63 MBtu/h])	1.16
50% (1,100 kW [3.75 MBtu/h])	1.14
25% (550 kW [1.88 MBtu/h])	1.15

Indoor Air Quality and Thermal Comfort

The primary function of a data center is to house and reliably support compute, storage, and networking equipment, termed by ASHRAE Technical Committee 9.9 (TC 9.9) as information technology equipment (ITE), and, as such, thermal comfort and indoor air quality for human occupation beyond statutory obligations is not a primary consideration. Data center industry environmental conditions relate to air temperature, humidity level, and air cleanliness for the ITE, both gaseous and particulate contamination.

The TC 9.9 thermal guidelines[1] internal thermal environments design criteria are as follows:

- Class A1 Recommended: 18°C (64.4°F) –27°C (80.6°F) DB
- –9.0°C (15.8°F) DP, 60% RH and 15°C (59°F) DP

The Kao Data cooling system is closely controlled to maintain the internal temperature within this range, and the only introduction of external air is by an ancillary air-handling system, which provides a nominal air change rate of 0.5 ach to 1 ach. This positively pressurizes the technical space to prevent dust ingress and air infiltration. This system includes functionality for humidification and de-humidification to ensure that the outside air introduced into the technical space adheres to the guidelines.

Data centers must be maintained to ISO 14644-1 Class 8. Coupled with the correct maintenance program, this level of cleanliness can generally be achieved by the following filtration levels:

- The recirculated air filtered with MERV 8 filters (G4/F5)
- Outside air filtered with MERV 11 (F6) or MERV 13 (F7)

The Kao Data pressurization air-handling system previously mentioned incorporates both MERV 8 pre-filters and MERV 13 filters to ensure particulate cleanliness is maintained.

In addition, manufacturers of IT equipment require data center operators to consider exposure to gaseous contamination to ensure equipment warranties are not put at risk. Research shows sulphur, chlorine, and ozone can, in varying compositions, contribute to electronic component reliability issues and accelerated corrosion. However, this requirement is lesser known and catered for across the data center industry. ASHRAE TC 9.9 published guidance on gaseous contamination thresholds,[2] referencing ANSI/ISA-71.04-2013, *Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants,* summarized as reactivity rate thresholds:

- Class: G1; Severity Level: Mild; Copper Reactivity: <300A (angstroms) per month
- Class: G1; Severity Level: Mild; Silver Reactivity: <300A (angstroms) per month

To ensure that the indoor air quality remains within these limits, real-time corrosion monitoring for both copper and silver reactivity monitors airborne contamination levels in accordance with ISA-71.04.2013, ensuring the customers' equipment warranties are never put at risk. This is unprecedented for a wholesale co-location data center in the UK.

Innovation

Through the innovative application of the thermal guidelines, this facility is the only wholesale co-location data center within the UK to operate without the requirement of mechanical refrigeration. The adoption of IEC technology has permitted reduced complexity in engineering design and services infrastructure, improving system reliability and availability.

During the design stage of the project, computational fluid dynamics (CFD) modeling was used as a tool to validate the concept of the cooling system, both internally and externally, to verify that the internal conditions would maintain weather conditions, without mechanical refrigeration (*Figure 3*).

Being able to test a prototype in the virtual environment not only enabled the efficiency and efficacy of the cooling system to be theoretically stress-tested and manage risk on a major capital investment, it also supported other design disciplines. For example, assessing the heat transfer across the ceiling allowed the architect to determine the specification for the thermal performance of the ceiling tiles.

Operation and Maintenance

The absence of refrigeration systems (compressors, condensers, evaporators, expansion devices, controls, and refrigerant medium and leaks) from the primary cooling system has offered significant operating expenditure (OPEX) benefits. Additionally, this significantly improved service availability, as system complexity was reduced and reliability increased due to the lower mean time to repair (MTTR).

The modular nature of the IEC technology also meant that the cooling system became distributed, reducing the standing redundant capacity often seen with centralized systems, which can depress operational efficiency under part-load conditions.

Redundancy is provided in the primary cooling system through N+1 capacity of the IEC and the process water treatment plant; this ensures that maintenance can occur during normal work hours and mitigates risk of loss of system effectiveness.

From inception, the transition across every milestone or stage of the building's life cycle was closely considered. Most relevantly, a soft landing approach was adopted in which the operations team, who would subsequently take possession and operational responsibility

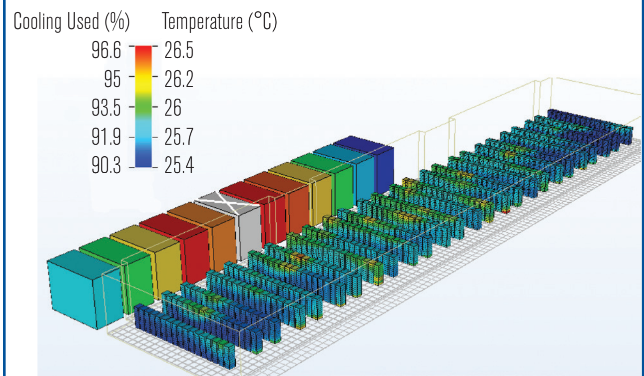


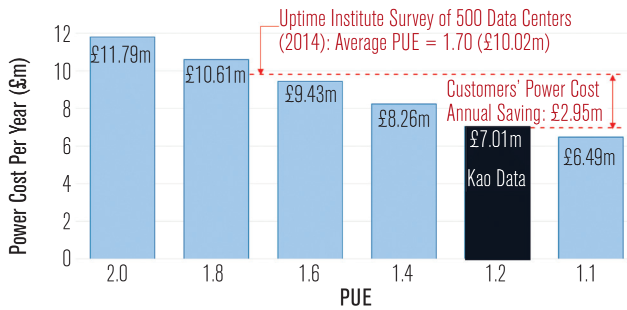
FIGURE 3 Screen shot from CFD modeling.

of the data center, joined the project team through all construction and the commissioning phases of the project. This approach facilitated knowledge transfer and enabled familiarization of systems in a non-live environment, which, in turn, resulted in a smooth handover of the building.

Cost-Effectiveness

The project was delivered under budget and on schedule, in part due to the reduced complexity in engineering design. The omission of mechanical refrigeration has eliminated part-load degradation of PUE, which is of significant importance within the economics of a data center, where utilization in the co-location market has historically varied between 50%–85% of maximum design capacity. In December 2018, the publication, Datacentre Dynamics, performed a supermicro survey of 361 data center professionals, in which the average PUE from respondents was 1.89, while 22% reported an average PUE of 2.0 or higher.

The analysis in *Figure 4* is based on a –8.8 MW (30.0 MBtu/h) data center, comprised of four 2.2 MW (7.5 MBtu/h) technology suites, 85% IT load utilization, £0.09/kW power cost, 24/7/365 operation, and a term of one year. Furthermore, total cost of ownership (TCO) can be considered as total real estate cost per year + power cost per year. As the total power cost correlates directly to the PUE, and the omission of refrigeration equipment has reduced both capital expenditure (CAPEX) and operational expenditure (OPEX), the analysis in *Figure 3* demonstrates that Kao Data will yield a significantly lower TCO for a comparable facility that maintains an internal technical environment



Analysis Based On:
- Operating 8,760 Hours Per Year
- 8,800 kW Campus Data Center Building At 85% Utilization
- £0.09 kwh Power Utility Cost

Industry typically represents PUE by considering data center performance at the peak design or contracted kW load. Coincidently, this approach aligns with the optimum operating efficiency of the power and cooling systems supporting the data center. This can lead to exceptional PUE at 100% load. However, in practice the data center kW load is dynamic, which has an adverse effect on the efficiencies of both the power and cooling systems, which have been optimized for 100% kW load. This impacts energy-efficiency, resulting in a proportionally higher PUE at part load. At Kao Data Campus, through innovative engineering, the PUE remains relatively constant from 20% to 100% of the kW load, resulting in potential energy savings against legacy solutions in the order of 25%-30% for the customer.

FIGURE 4 Average annual operating PUE. Notes: Uptime Institute survey data: 1.89 (2011), 1.80 (2012), 1.67 (2013), 1.70 (2014)

using refrigerant-based cooling, resulting in a higher PUE.

Environmental Impact

The absence of refrigeration systems has minimized the potential global-warming and ozone-depleting impact on the environment, in addition to carbon emissions.

To demonstrate this, *Table 2* compares data for data centers, with PUEs of – 1.21 (Kao Data), 1.58 (2018 industry average), and 2.0 (2011 industry average), in which the PUE has been translated into an equivalent CO_2 emission based on the Carbon Trust (2011) conversion factors (www.carbontrust.com).

Notably, the Building Research Establishment Environmental Assessment Method (BREEAM) uses scientifically based sustainability metrics and indices that cover a range of environmental issues. Its categories evaluate energy and water use, health and well-being, pollution, transport, materials, waste, ecology, and management processes. In recognition of the minimized environmental impact of the facility, Kao Data was awarded a BREEAM rating and certificate of "Excellent" for both the design and construction.

Table 2 Carbon dioxide calculation based on Carbon Trust conversion factors (2011), www.carbontrust.com.

Simulated Thermal IT Load	PUE	Total Power (kW)	kW Difference	Equivalent ($kgCO_2$)
100% (2,200 kW)	1.21	2,662	462	242.4
As Compared to a Typical Data Center, Where the PUE is 1.58:				
100% (2,200 kW)	1.58	3,476	1276	669.4
As Compared to a De-Rated Data Center, Where the PUE is 2.0:				
100% (2,200 kW)	2.0	4,400	2200	1,154.1

Conclusion

It has been demonstrated that through innovative application of appropriate technology and taking an opportunity-risk based approach, the ASHRAE thermal guidelines can be maintained without the use of a mechanical refrigeration plant.

The absence of a refrigeration plant introduces a range of benefits in the form of both energy efficiency and sustainability, as well as longer-term OPEX savings for both the data center customer and operator.

Through the omission of a mechanical refrigeration plant, Kao Data Campus sets the standard for data center design construction and operations, reducing the environmental impact of data centers in a manner that also makes both commercial and economic sense. In a growing data center industry, driven by consumer demand for data services, the application of appropriate technology and a considered design approach provide a global opportunity for data center owners and operators to bolster their corporate social responsibility credentials, as we strive toward delivering the ultimate in sustainable software defined data centers.

References

1. ASHRAE. 2015. *Thermal Guidelines for Data Processing Environments, 4th Edition*. Atlanta: ASHRAE.

2. ASHRAE 2013. *Particulate and Gaseous Contamination in Datacom Environments*, *2nd edition*. Atlanta: ASHRAE. ■

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