

White Paper: Sustainability Metrics Considerations – PUE

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1. Executive Summary

Open Compute Project (OCP) Sustainability project is working on a mission to enable progress towards industry sustainability goals by addressing unique challenges and opportunities presented within the OCP ecosystem. Within the OCP Sustainability project, Data Center Efficiency Metrics (DCEM) workstream is working on identifying opportunities to improve data center efficiency related to sustainability. The Power Usage Effectiveness (PUE) metric is widely used to characterize and report overall data center infrastructure efficiency, but variability in data center infrastructure and in the measurement and reporting of PUE make it hard to compare data centers using PUE numbers and recommend areas for improvement. Even though the global annual average PUE reported in 2022 was 1.55[1], many data centers already operate below PUE of 1.10 (> 90% infrastructure efficiency). Just by looking at the PUE number, it is difficult to determine changes needed for further efficiency improvements.

This paper provides an overview of PUE measurement and highlights several complexities involved in comparing PUE metrics across data centers. This paper will introduce a few concepts to consider for augmenting PUE to increase accuracy and foster further improvements in data center efficiency. The motivation of this paper includes identifying some of the changes necessary for upcoming regulations related to data center efficiency.

[1] Source: https://uptimeinstitute.com/about-ui/press-releases/2022-global-data-center-survey-reveals-strong-industry-growth

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2. List of Abbreviations

CUE - Carbon Usage Effectiveness
GWP - Global Warming Potential
PDU - Power Distribution Unit
PUE - Power Usage Effectiveness
PSU - Power Supply Unit
UPS - Uninterruptible Power Supply
WUE - Water Usage Effectiveness
DTC - Direct-to-Chip
HEX - Heat Exchanger

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5. Introduction

As we work towards making improvements in the sustainability area influenced by Open Compute Project (OCP) related ecosystem, we need to identify opportunities to make improvements. This white paper summarizes several improvement opportunities identified by Data Center Efficiency Metrics (DCEM) workstream under the OCP Sustainability project related to PUE.

6 Power Usage Effectiveness (PUE)

This section introduces PUE details and walks through the impact of various factors such as load variability, power delivery architecture, and data center cooling architecture on PUE.

6.1 PUE History and Definition

The PUE metric was originally defined in 2007 by The Green Grid, a global consortium of IT industry leaders. Subsequently 7x24 Exchange, ASHRAE, The Green Grid, Silicon Valley Leadership Group, U.S. Department of Energy Save Energy Now Program, U.S. Department of Energy Federal Energy Management Programs, U.S. Environmental Protection Agency's ENERGY STAR Program, United States Green Building Council, European Commission Joint Research Centre Data Centres Code of Conduct, Trade and Industry of Japan's Ministry of Economy, Japan's Green IT Promotion Council and Uptime Institute involvement and recommendations helped further accelerate industry adoption of PUE.

PUE has been adopted as an ISO standard ISO/IEC 30134-2:2016. Based on point of energy measurement within the data center, PUE is categorized as follows:

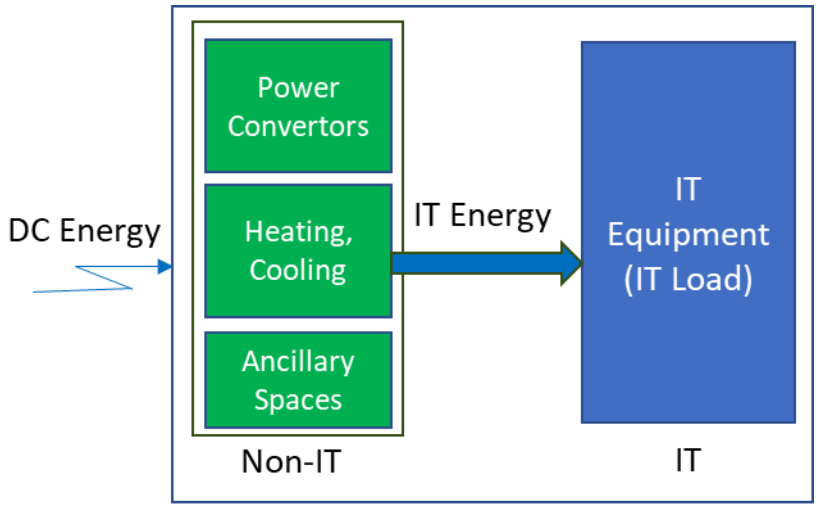
PUE Category 1 (PUE_1) — based on UPS output, provides a basic level of resolution of energy performance data.
PUE Category 2 (PUE_2) — based on PDU output, provides an intermediate level of resolution of energy performance data.
PUE Category 3 (PUE_3) — based on IT equipment input, provides an advanced level of resolution of energy performance data.

Figure 1 represents a breakdown of the total energy consumption for a typical data center. PUE is defined as ratio of Total Data Center Energy to IT Equipment Energy as shown below:

$$PUE = \frac{Total\ Data\ Center\ Energy\ Consumption}{Total\ IT\ Energy\ Consumption} = 1 + \frac{Total\ Data\ Center\ Non{-}IT\ Energy\ Consumption}{Total\ IT\ Energy\ Consumption}$$

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Figure 1 Data Center Energy Blocks



6.1.1 Definitions

Refer to "Recommendations for Measuring and Reporting Overall Data Center Efficiency" for definitions. The following are the additional definitions used in this document.

Total non-IT Energy: The total non-IT energy is the weighted sum of the energy consumption of all the non-IT equipment for a given measurement period. This includes energy consumed by power convertors, energy used for heating and cooling and energy consumed by ancillary spaces. This is inclusive of anything considered one structure of a datacenter but identified as one building or group set of IT. If the data center is in a mixed use building that may share data center infrastructure energy for other uses, proper accounting of data center and IT equipment consumed energy is needed for accurate representation of total non-IT Energy. For PUE calculations purposes, accounting of non-IT energy within the system and rack level such as fan energy consumption, idle energy consumption, heat exchanger energy consumption are generally not comprehended.

Load: Load is the unit represented in percentage output performance produced by the unit of compute such as system, rack or data center as compared to maximum possible performance output the unit can generate. For example, when the system is idle, no output performance is generated and hence its load is 0%. But when the system is producing maximum output, it is operating at 100% load. In most systems, the power consumed by the system may not be linear to the load. It is also referred to as the percentage of peak capacity of the compute unit.

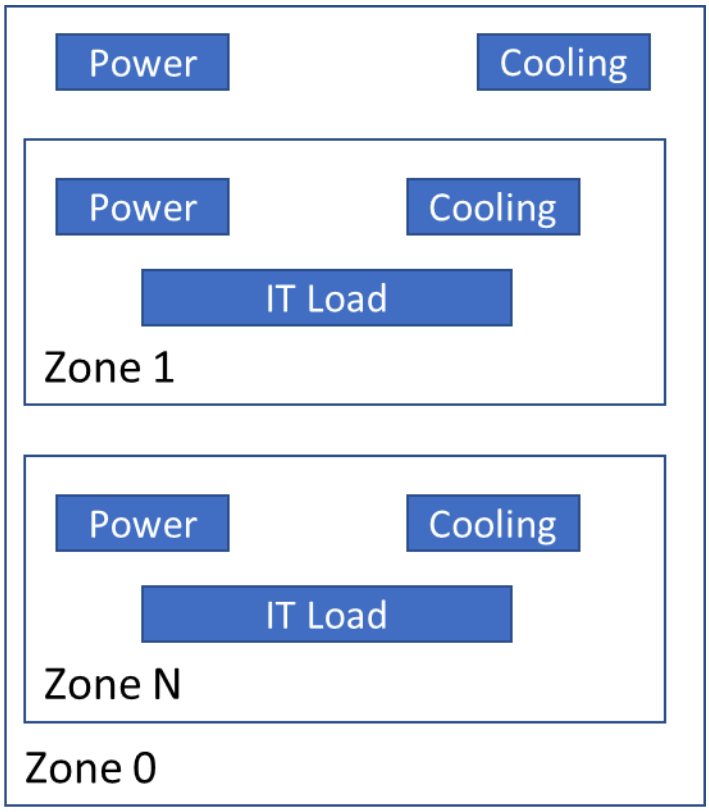
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6.2 Partial PUE

The PUE is measured at the whole data center level. IT equipment often installed or upgraded as portions within the data center, sometimes this is referred to as modular data center. Having the ability to measure PUE contributions of these portions of the data center helps to manage and fine tune these portions as needed to improve PUE. The ability to manage energy efficiency for a portion of a data center is called partial PUE (pPUE).

As shown in Figure 2, a data center could be divided into multiple portions (Zones).

Figure 2 Partial PUE



For each Zone, the pPUE could be defined as follows:

$$pPUE = \frac{Total\ Energy\ Consumption\ Inside\ the\ boundary}{Total\ IT\ Energy\ Consumption\ Inside\ the\ boundry}$$

This results in $pPUE_{Zone1}$, $pPUE_{Zone2}$, … $pPUE_{ZoneN}$

Data Center PUE could be computed from these partial PUE as follows:

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$$PUE = \frac{\sum_{i=0}^{N} DC\ Source\ Energy\ for\ Zonei}{\sum_{i=0}^{N} IT\ Source\ Energy\ in\ Zonei} = \frac{\sum_{i=0}^{N} NonIT\ Source\ Energy\ for\ Zonei}{\sum_{i=0}^{N} IT\ Source\ Energy\ in\ Zonei}$$

The PUE computed using the above method and PUE computed using the (NonIT Source Energy/IT Source Energy) should match.

6.3 PUE Measurement

6.3.1 Static PUE

Static PUE (sPUE) is a computed demand-based PUE rather than measured consumption-based PUE. This metric is generally used during the design phase of a data center. Incremental design phases may be required to plan the installation of major equipment upgrades. The sPUE could be computed for various IT load points such as max load (max TDP), idle load and optimal load. Optimal load is system and workload dependent. For example, one might consider determining pPUE with sPUE for a collection of system/racks configs and another pPUE with sPUE for another collection of system/racks configs to finalize optimal configuration.

6.3.2 Dynamic PUE

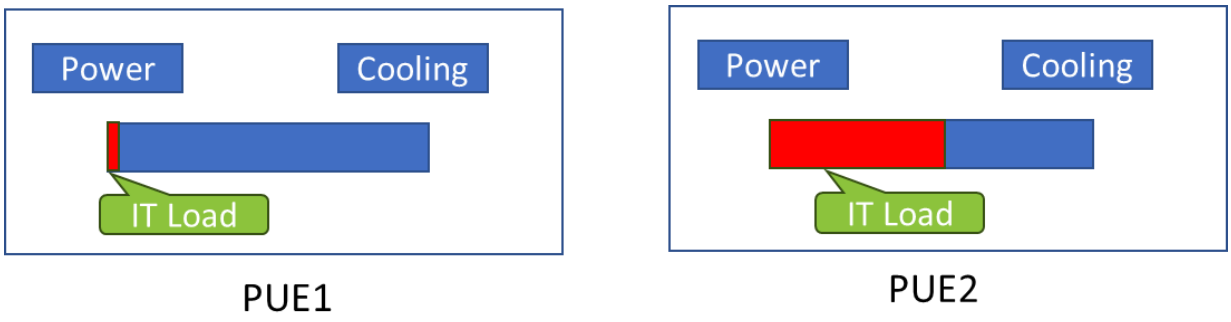
Dynamic PUE is the measured consumption-based PUE under normal operating conditions. When PUE is reported, it is assumed that the dynamic PUE is reported unless it is denoted by prefix or suffix. For example, PUE@wue indicates PUE number at WUE number. Similarly, pPUE@zone1 indicates a partial PUE for zone1 of the data center.

6.3.3 IT Load Variability

In most data center designs, the ratio between non-IT energy and IT energy is not uniform across the range of IT load conditions, thus the PUE measurement varies based on the IT load. As shown in Figure 3, the PUE1 is measured when load is low (<10%) and PUE2 is measured when IT load is high (>50%). Here PUE2 could be lower than PUE1, but the total non-IT energy represented by PUE2 load may be higher than that for PUE1. If the reported PUE does not include load factor, it is difficult to compare PUE across zones/data centers.

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Figure 3 PUE and IT load



6.3.4 Sampling period

Sampling period is the time interval in which the energy measurement is performed for PUE computation.

Typically, 15 minutes, hourly, daily, weekly, monthly and annual measurements are considered. Indication of sampling period in the PUE would be helpful for comparison purposes.

6.3.5 Measurement and Reporting

Increased improvement in sustainability comes with increased transparency both internally within the data center and externally. Currently PUE measurement and reporting of data centers are voluntary in most geographies. "*Recommendations for Measuring and Reporting Overall Data Center Efficiency*[2]" paper recommends energy measurement categories and reporting recommendations. OCP sustainability related work streams are working towards enhancing metrics related to OCP systems.

6.4 Power Delivery Architecture

6.4.1 Data Center Power Converters

The data center energy could include electricity (utility, on-site solar), natural gas, fuel oil or other forms of fuel. These sources of energy utilize the power delivery components such as generator, solar panels, switchgear, batteries and power distribution units to deliver the energy to the IT equipment to run IT load. Converting energy from one form to another to reach the IT equipment would incur losses. These energy losses are accounted as part of the non-IT energy. In some cases, for example, batteries and local electricity generation are utilized to maintain the service through utility outages during PUE reporting period. Inclusion of this information during the PUE reporting would be helpful for the PUE comparison.

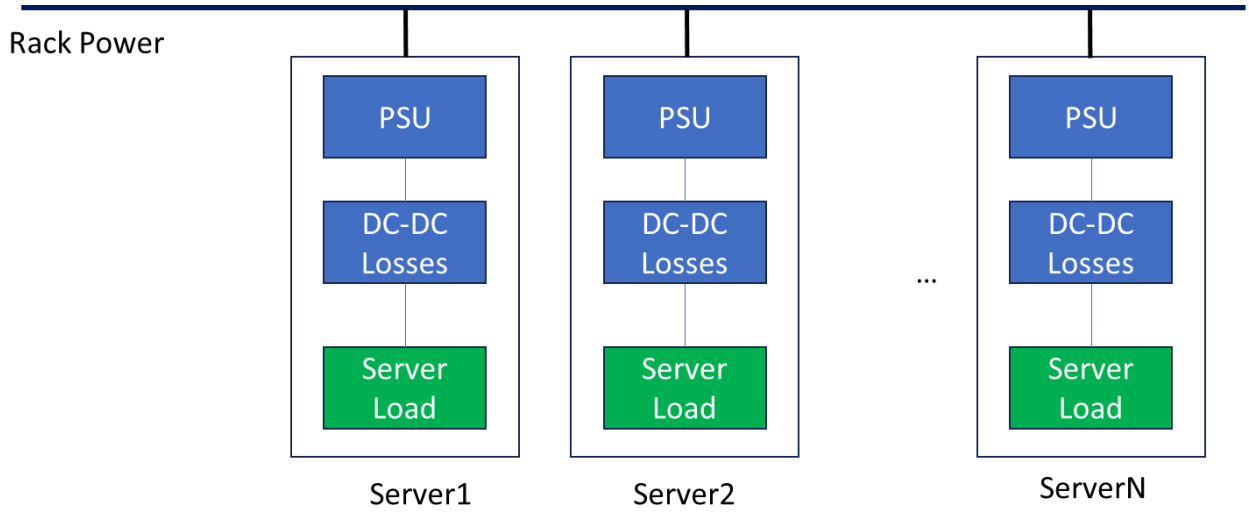
[2] https://www.energystar.gov/ia/partners/prod_development/downloads/Data_Center_Metrics_Task_Force_Recommendations_V2.pdf?5311-22ed

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6.4.2 Traditional Rack Server

In the traditional rack-based design, as shown in Figure 4, each server contains a power supply unit (PSU) which converts AC inlet power to DC load power. The PSU is connected to the rack (AC) power connector. In this design, power conversion losses are incurred in each PSU unit in each server. In addition to the PSU, generally DC-DC converters (voltage regulators) are used to convert 12V or 5V DC power supplied by the PSU to much lower DC voltages demanded by IT components. Power losses are incurred in each DC-DC conversion too. Even though these power losses are endemic to rack level power delivery, they are accounted for in the IT energy rather than in non-IT energy in the traditional PUE calculation.
In pursuit of improving overall DC efficiency, it would be preferable to establish a more granular metric or set of metrics which distinguishes between these incremental conversion losses and the actual IT load energy.

Figure 4 Traditional Rack Power

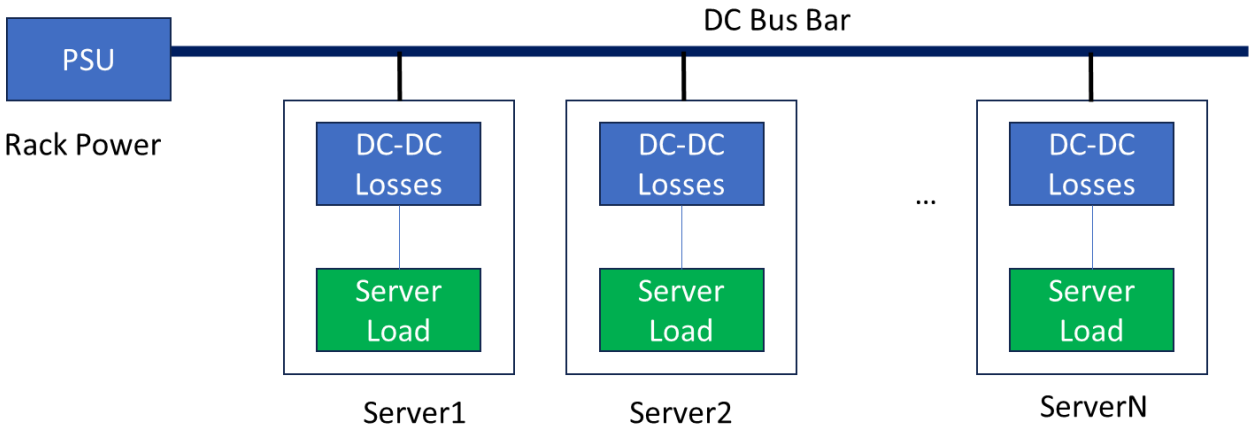


6.4.3 DC Bus Bar

In the DC Bus Bar based rack design shown in Figure 5, a common PSU at rack level converts AC inlet power to (high voltage) DC power distributed to each server in the rack by way of one or more DC Bus Bars (e.g.: one for each of 3 AC power phases). In this design, the PSU conversion loss is shared across the servers in the rack, resulting in a lower net loss than would be accumulated across PSU instances in each server. Each server in the rack then uses a power distribution board (PDB) and local DC-DC converters (voltage regulators) to convert the high-voltage DC Bus Bar input voltage to the various low-voltage DC supply levels demanded by IT components. OCP has Open Rack V1(ORV1), Open Rack V2 (ORV2) and Open Rack V3 (ORV3) designs. The ORV1 supports 12V; ORV2 supports 12V and 48V; ORV3 supports 48V busbar. The 12V design results in higher current and higher IR losses unless higher cost (lower gauge) copper rails are used as compared to 48V design. Incremental losses are incurred in DC-DC conversion, and again the current PUE model accounts for all these power delivery losses as part of IT energy rather than non-IT energy.

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Figure 5 DC Bus Bar based Rack



6.5 DC Cooling Architecture

IT equipment consumes power and generates heat. Data Centers utilize various methods to cool the IT equipment and maintain DC ambient temperatures within required operating ranges. Infrastructure associated with DC cooling also consumes energy which is properly accounted for as non-IT energy for purposes of PUE.

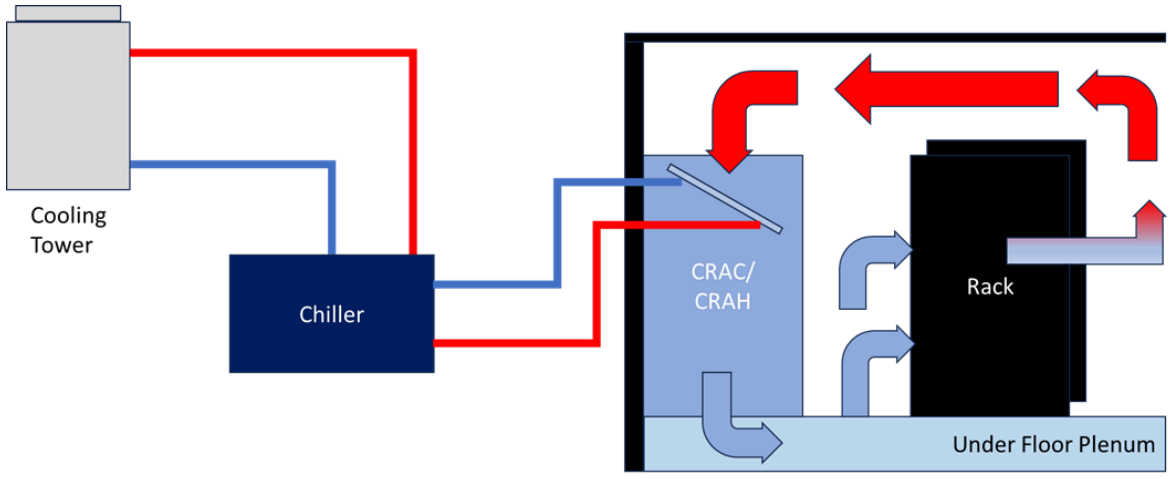
6.5.1 Traditional Cooling

In the traditional data center design, the heat from IT equipment is circulated by fans through air. The hot air is cooled using CRAC/CRAH, chiller and cooling towers as shown in Figure 6. Even though none of the fan power is directly attributable to IT services, the fraction of fan power dissipated inside the racks is currently accounted for as part of IT energy.

In pursuit of improving overall DC efficiency, it would be preferable to establish a more granular metric or set of metrics which distinguishes between rack level fan power overhead and actual IT load energy.

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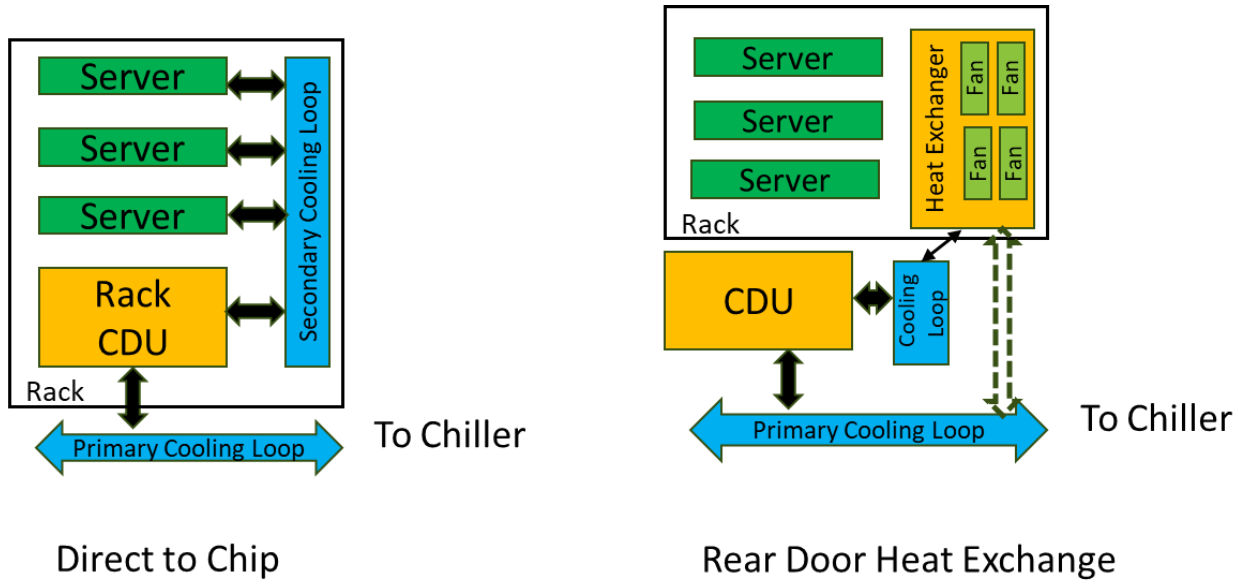
Figure 6 Traditional Data Center Cooling



6.5.2 DTC and Hex

Direct to Chip (DTC) and Rear Door Heat Exchanger (Hex) solutions are designed to move the heat quickly to increase the rate of heat exchange and thereby increase effective cooling capacity. As shown in Figure 7, the DTC and Hex designs utilize a Coolant Distribution Unit (CDU). In the case of DTC, each server is connected directly to the coolant flow. In case of Hex, the server heat is circulated by fan through air and the CDU cools the air through coolant. The CDU and fans consume energy to exchange and reject the heat from the servers, but all or part of that energy is accounted for as part of IT energy in the traditional PUE calculation.

Figure 7 Direct to Chip, Read Door Heat Exchange

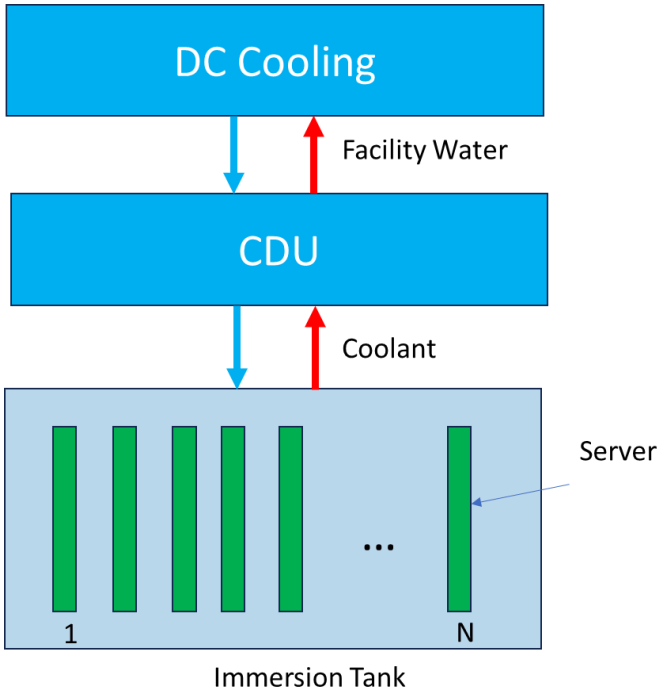


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6.5.3 Immersion Cooling

In the immersion cooling method, servers are immersed in the dielectric fluids. This enables increased efficiency, performance and reliability due to high heat transfer rate, denser packing, elimination of fans, stable temperature and reduced contamination, and other environmental benefits. As shown in Figure 8, immersion cooling utilizes the CDU to circulate coolant in the immersion tank and the CDU uses the facility water to cool the coolant. Even though CDU and Immersion tank are not performing IT services, the energy associated with their operation is accounted for as part of IT energy for PUE computation.

Figure 8 Immersion Cooling



6.5.4 Emerging Cooling and its impact on PUE summary

Table 1 shows examples of various cooling methods and their associated energy loss. Even though cooling methods are not providing IT services, these losses are accounted for as part of IT energy in the PUE computation.

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Table 1 Example of Emerging Cooling and its impact on PUE

	Server Fans	Server Fan Duty Cycle	Thermal Energy Loss at Server Level	Cooling Energy Accounting
Traditional Rack Server	Yes	Up to 100%	~10% of Server Power	Fans –> IT energy
Rack Server + Hex	Yes	Up to 100%	~10% of Server Power	Fans –> IT energy CDU -> IT energy, DC energy
Rack Server + InRow Cooler	Yes	Up to 100%	~10% of Server Power	Fans –> IT energy CDU -> IT energy, DC energy
Rack Server + DTC	Yes	< 50%	< 5%	Rack CDU -> IT energy CDU -> IT energy, DC energy
Tank Immersion Cooling	No	NA	0	CDU energy – shared between IT and DC

6.6 IT Load Consideration

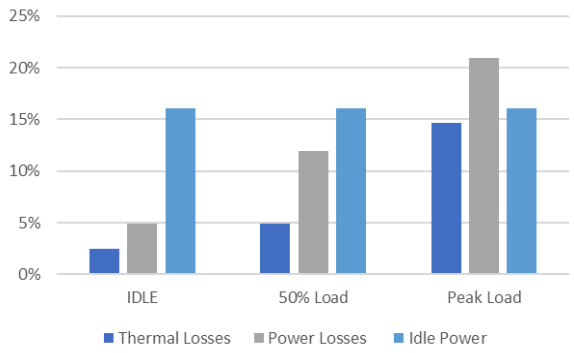
IT equipment contains compute, storage, network and peripheral devices. These devices are designed with maximum Thermal Design Power (TDP). TDP refers to the maximum amount of heat that a server is designed to dissipate under its maximum theoretical workload.

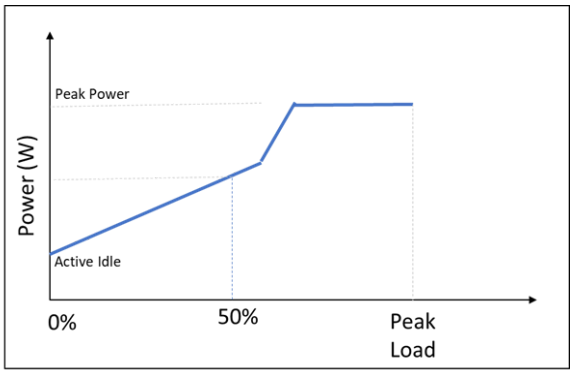
6.6.1 Server Load and Power Consumption

As shown in Figure 9 Figure 8, power consumption of the server varies based on the load. When the server is idle it does not perform any IT services but dissipates a material fraction of its peak active power while waiting for service workloads to be scheduled. The power associated with this “active idle” state varies between servers, and is accounted for as part of IT energy in the PUE computation.

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Figure 9 Hypothetical Server load and Power Consumption





It is evident in the left chart of Figure 9 that disentangling actual IT component power from overhead and losses across the server load line will be complicated, because both power and thermal losses scale with the load.

In pursuit of improving overall DC efficiency, it would be preferable to establish a more granular metric or set of metrics which distinguishes between server level idle power overhead, power and thermal losses, and actual IT load energy.

It is also evident that load level or utilization can heavily influence the measured PUE, thus inclusion of the load factor in PUE (example PUE@load40%, PUE@load60%) would enable better PUE comparisons.

6.7 Geo Impact

Energy consumed for data center cooling is heavily dependent upon the data center source water temperature and ambient air temperature and humidity factors. These factors vary greatly based on geographic location and fluctuate day to day within the same geo location. For example, identical data centers running the same mix of workloads in Ireland vs. Singapore will operate at different PUE levels since Ireland is materially cooler than Singapore on an average annual basis.

Inclusion of cooling input factors as part of PUE reporting would enable better PUE comparisons. Since weather history for most of the geos are commonly available, tagging PUE with geo location using GPS co-ordinates such as PUE@ (1.3521° N, 103.8198° E) to indicate PUE@Singapore, and PUE(53.4129° N, 8.2439° W) to indicate PUE@Ireland would enable improved understanding of the cooling input variations. When geo information is not available, we need to devise a mechanism to include a cooling input data set like weather data and denote with PUE@cooling-dataset-url.

6.8 Water Impact

Sustainability requires more than just improved energy efficiency metrics. If the data center uses water for cooling, metrics on efficient water use also must improve. Increased use of colder water may result in better

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PUE, but this approach may be less sustainable overall. It is necessary to combine PUE with a complementary metric like Water Usage Effectiveness (WUE) and optimize the resulting net combined metrics.

$$WUE = \frac{Data\ Water\ Usage}{Total\ IT\ Source\ Energy}$$

Reporting WUE in conjunction with PUE would be helpful to understand the WUE impact for PUE comparison (example, PUE@WUE#).

7 Future work (Outlook for 2024-2025)

7.1 Alignment with Other Work

In OCP, each project plays a role in sustainability. As we work on defining and improving sustainability related metrics, alignment within the OCP projects such as Sustainability, Data Center Facility, Cooling Environments, Rack and Power, Server, Storage, Networking and others are needed. It is also important to align with industry organizations that work on sustainability such as The Green Grid, ASHRAE, Uptime Institute, The iMasons Climate Accord, government agencies and regulatory bodies for alignment and to create an ecosystem for deployment.

7.2 Future Work

OCP DCEM workstream in Sustainability project is planning on the following major work to make improvement on the sustainability related metrics.

- Enhance classification of non-IT and IT energy buckets.
- Finalize definition of metrics to comprehend the enhanced non-IT and IT energy classification.
- Alignment with OCP projects and sustainability related working bodies.
- Measurement framework for non-IT and IT energy for OCP systems.
- Modeling framework for PUE characterization in data centers.
- OCP profile for sustainability metrics including the enhancement metrics, certification, labeling, reporting, etc.
- Decide if performance (work) per Watt IT energy a feasible metric to pursue to measure data center efficiency. Example: Server Efficiency Rating Tool (SERT) proposed by U.S. Environmental Protection Agency (EPA).
- Complete GWP and CUE metric review and finalize PUE related metrics improvement opportunities.

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8 Conclusion

This white paper provides a summary of initial analysis performed on PUE by the OCP Sustainability project DCEM workstream. The paper identifies a few areas of IT energy that need to be accounted for in non-IT energy for proper PUE representation. To achieve sustainability goals, PUE needs to be evaluated in conjunction with other sustainability metrics. Tagging PUE @geo @wue @load, etc. would enable PUE comparison across dissimilar data centers to identify and pursue improvement opportunities. Additional work is needed to bring improvement to PUE and to sustainability goals. The work towards improving these matrices would enable data center designs to meet new regulatory requirements.

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9 References

Resources for more information

1. Recommendations for Measuring and Reporting Overall Data Center Efficiency
2. Harmonizing Global Metrics for Data Center Energy Efficiency
3. PUE™: A Comprehensive examination of the metrics
4. Portfolio Manager Technical Reference: Thermal Conversion Factors

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11 About Open Compute Foundation

At the core of the Open Compute Project (OCP) is its Community of hyperscale data center operators, joined by telecom and colocation providers and enterprise IT users, working with vendors to develop open innovations that, when embedded in products, are deployed from the cloud to the edge. The OCP Foundation is responsible for fostering and serving the OCP Community to meet the market and shape the future, taking hyperscale led innovations to everyone. Meeting the market is accomplished through open designs and best practices, and with data center facility and IT equipment embedding OCP Community-developed innovations for efficiency, at-scale operations and sustainability. Shaping the future includes investing in strategic initiatives that prepare the IT ecosystem for major changes, such as AI & ML, optics, advanced cooling techniques, and composable silicon. Learn more at www.opencompute.org.

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