Quantitative analysis of energy and financial savings for full-year operation of modular data center relative to raised floor environment

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Abstract

The data center industry is filled with dialogue around the energy performance of data centers, but it is difficult to compare the performance of one data center to another due to differences in design, geography, customer type, measurement method and other factors, not to mention the credibility of the claims. When introducing a new technology platform, demonstrating a financial benefit is critical to adoption, but in the face of such challenges in performance benchmarking it can be difficult to prove superior operating costs. This paper describes a first-of-its-kind study that accurately and effectively compared the energy performance of modular data center technology to the performance of a traditional raised floor data center.

IO, APS and DNV Kema (Now DNV GL) evaluated the performance of IO’s modular data center platform compared to a raised floor environment. The experiment isolated the difference between modular and raised floor environments over a full year of actual use, and normalized for factors such as weather conditions, envelope design, chiller plant efficiency and system utilization. The study used data from 2012.

The modular environment demonstrated a 44% reduction in energy waste (19% energy cost savings). The estimated cost reduction amounted to more than $200,000 per megawatt (MW) of IT power load per year based on the site’s electricity rate at the time, $0.07/kWh.

Keywords: Energy, efficiency, climate, cost, emissions, data center, modular, raised floor
Data centers are the backbone of the modern economy. Our businesses and infrastructure are being digitized, and our digital work takes place within the walls of a data center.

The data center forms a part of the larger energy-water-information system, represented by at least three discrete sections. Examining this overall system is essential to understanding how much value we create per unit of input, whether that input is money, energy, water or byproducts like carbon emissions or raw materials usage. As illustrated in Figure 1, there is the section of the system that captures and transmits energy to the data center (utility), the data center itself, responsible for power conditioning, cooling, security and other support systems, and finally the IT system, housed within the data center and responsible for turning energy into information. Performance of the overall system requires a holistic view and none of these systems should be optimized at the unintended expense of the other. As a colocation data center provider, IO is primarily responsible for the middle portion of the supply chain, the efficiency of which is the focus of this study. Nonetheless, we focus on driving change upstream and downstream of our location in the digital supply chain, by engaging with utilities and energy markets, suppliers and our downstream customers.

To inspire the industry to rethink the future of data center design, IO partnered with Arizona Public Service Company (APS), the largest electric utility in Arizona, and DNV KEMA, the leading authority in energy-related testing, inspection and certification. The three companies compared energy efficiency and cost savings between modular and construction-based data center designs. IO is uniquely positioned to conduct such a study because it operates both traditional and modular environments.

**Figure 1. The water-energy-information system**
Background and general assumptions

The data center industry relies on an efficiency benchmark known as Power Usage Effectiveness (PUE).\(^1\) The study focused on this metric as the proper measurement of system performance. PUE is calculated as total power input compared to delivered Information Technology Equipment (ITE) power.\(^2\)

\[
PUE = \frac{\text{Total facility energy}}{\text{ITE energy}}
\]

The PUE metric provides a comprehensive view of performance similar to the auto industry’s Miles Per Gallon (MPG) or the air conditioning industry’s Seasonal Energy Efficiency Ratio (SEER). However those metrics are structured in the form of (Useful Output/Input Energy) whereas PUE is inverted: (Input Energy/Useful Output). As a result, in the case of MPG and SEER, a higher number is better, while with PUE performance improves as your metric decreases towards the ideal value of 1.0.

PUE comes under criticism for a few factors

- It falls short of measuring useful work. In fact, MPG falls short in a similar way. Two vehicles with the same MPG may have differing performance if they carry a different number of passengers or payload. A mile traveled can have different utility. Similarly, though PUE measures the efficiency of delivering a unit of energy to IT equipment, it does not encompass how usefully that unit of energy is put to work.
- Test conditions are not standardized. Many of the claims in the marketplace have to do with “best-case” or “design” PUE, rather than measuring real-world performance over time. There can be large variation between ideal PUEs and those in the real world, especially in cases of very low system utilization. At zero load, PUE for even the most efficiently designed data center is infinite.

**Figure 2:** IO Phoenix, the site of the benchmarking study, is home to traditional DC1.0 and modular DC2.0 environments.
Despite its shortcomings, PUE is the appropriate metric for this study. The study described herein overcame each of them as follows: Both Data Center 1.0 (DC1.0) and Data Center 2.0 (DC2.0) environments in Phoenix have the same variety of customers. Though PUE falls short of measuring the work done by the customers’ IT equipment, neither environment benefits from that shortcoming in this study. The study used the same standards for measuring PUE across both environments and used a full year of actual operating conditions. The results are calculated over a full year by taking multiple PUE measurements over time to calculate energy consumption, both input and output, for both environments and that annualized PUE is used for the comparison.

General assumptions

- PUE is the appropriate measure for the study.
- Similar customer base – large, small, homogeneous, heterogeneous, steady, intermittent, are all consistent across the two environments, making the study a good comparison.
- Any error introduced due to sampling rate or meter accuracy is consistent across both environments.
- Auxiliary loads have been subtracted wherever out of scope and added appropriately when necessary.

Problem statement

IO operates a 587,000 square foot data center in Phoenix, Arizona, the site of the study performed in conjunction with APS and DNV KEMA and typically referred to as IO.Phoenix. The group set out to understand three specific questions. Does a modular data center product show quantifiable energy savings? Given the operating environment in IO.Phoenix, is it possible to evaluate a full year of performance data to arrive at a real-world, rather than a “best case” performance difference? Can the experiment be constructed with sufficient control to isolate the only experimental variable as the difference between modular and raised floor design, and therefore emerge with a performance gain factor that is applicable universally across raised floor and modular data centers?
Methodology

Parameters were put in place such that the researchers could draw a fair comparison and achieve the three goals set out above. Those parameters included:

**Same geography.** All numbers from this report come from IO.Phoenix, which contains traditional DC1.0 and modular DC2.0 data center environments. This means that the weather conditions faced by the building’s cooling system, a major source of energy overhead for a mechanically-cooled data center such as IO.Phoenix, were identical.

**Same chiller plant.** In addition to having the same weather conditions, the two environments were served by the same chiller plant. This fact added complexity to the analysis, given that the energy consumed by the chiller plant had to be attributed to each environment appropriately. However, overall it was a positive aspect of the study, because it meant that chiller efficiency was a control variable, and therefore the efficiency results do not stem from any differences in chiller plant performance.

**Electrical metering schematic**

![Simplified electrical architecture and metering location diagram for the data center backplane.](image)

Figure 3: *Simplified electrical architecture and metering location diagram for the data center backplane.*
Figure 2 shows an electrical schematic of the site backplane, including the chiller plant. In addition to relying on direct data from the chiller plant, an eQuest DOE2 simulation was created for the chiller plant systems and the building core and shell. Simulation results were then compared to utility data to calibrate and validate the performance of the simulation model. The simulation had the added benefit of confirming that neither environment was benefitting from a change in overall system performance as the load in the building increased. (The modular environment was built second, and therefore increased the load on the chiller plant. In doing so, the chiller plant could have been pushed into a higher or lower efficiency operating regime). In the end, simulation results confirmed steady chiller plant operating efficiencies around .8kW/Ton, as expected, held steady throughout the change in load, attributable to the high degree of variable control on chiller plant equipment such as chillers, pumps and cooling tower fans.

**Same building, same envelope.** The study looked at the performance of a traditional raised floor environment and a modular environment within the same building. The IO.Phoenix modules are housed within a data center, though not all of IO’s deployments have this “nested” scenario. Nevertheless, the analysis included the extra energy overhead that the design requires in terms of space lighting and ventilation/air conditioning, located in the space surrounding the modules. The building envelope is the same for both environments. As a result, the loads on the ventilation and air conditioning system were attributed on a per-square-foot basis. This was thought to be a conservative assumption, seeing as the modules are an insulated system, taking care of all cooling needs of the IT within the six sides of the module, while the open raised floor environment may burden the roof-mounted air handlers with additional cooling not associated with the performance of the CRACs that cool and pressurize the raised floor.

**Same operator.** IO staff monitor and maintain both environments on behalf of customers and IO. Therefore where some performance analyses might fall short of providing a valid control and experimental group, the only gains or losses in performance associated with one environment over the other would have to be attributed to the design and performance of the systems themselves, rather than the personnel, who were identical across both environments.

**Same customer demographics.** Within both the traditional and modular environment, IO serves customers of varied IT characteristics including customer size, IT power density, and design homogeneity.

**Utilization.** Full year utilization of 200 kW Modular units was used to project annual savings across both the modular and the DC1.0 environment. While the industry is flooded with claims of “design PUE” and “PUE as low as” there is not a standardized way of analyzing real world operating conditions – similar to what the auto industry benefits from in the EPA estimates for city and highway driving conditions to normalize MPG claims.
Data capture

Modular energy performance calculation explained

For each operating condition, binned into 5kW demand ranges, an analysis of module energy overhead was conducted consistent with the IO real-time PUE calculation methodology. A consumption profile was created to quantify the expected amount of time a module would operate within each bin, on average, during a year. For data modules, the energy overhead, also referred to as support power, consists of electrical load caused by the air handlers’ variable speed Electronically Commutated Motors (ECMs), LED lighting, fire detection and suppression system, make up air handling unit with humidification and dehumidification controls and the overall system monitoring and control system. Support loads (primarily fan power) increase as load increases, but this “marginal” overhead drives average overhead downward. Therefore, as IT load increases the average Data Module energy overhead decreases as a percentage of load. There is a direct analogy to microeconomics of any production environment, where the data center output is measured in terms of kWh of IT load delivered to customer and where there are fixed and variable production (energy use) costs.

Figure 4: Simplified electrical hierarchy and metering locations for the modular data center environment.
Similarly, Power Modules see their own energy overhead, or support loads, increase as the power put through them increases. Power Modules were deployed in a 2N configuration and each pair serves approximately 15–24 Data Modules, depending on utilization rates achieved by the customers within those data modules. Just like the Data Modules, Power Modules’ overhead decreases on a per unit basis, because although variable overhead rises as load increases, marginal overhead is less than average overhead, driving the average overhead toward the marginal “energy cost” of delivering a kWh of IT energy to customer.

With these performance curves calculated, derived from a full year of module operating performance across all modules in IO.Phoenix, the energy burden upstream of the IT equipment—from the support power of the Data Modules and the Power Modules to the Unit Substation transformer losses—were all known as a function of load. This does not paint the full picture of DC2.0 energy overhead, however. The loads associated with maintaining a habitable environment in the data hall surrounding the modules, as described earlier had to be added and were treated on a per-square foot basis. Beyond that, the primary additional factor to be considered is chiller plant load.

### Treatment of chiller plant burden

During the year in which the study took place, the raised floor and modular environments were served by shared chiller plant infrastructure consisting of chillers, pumps and evaporative cooling towers. Chiller plant input energy was calculated and validated from multiple methods: Direct measurement from monthly meter readings, simulation using DOE2 eQuest and validation against total site energy as measured by the utility meter and other meters within the site. That electrical input into the chiller plant was then proportioned to the traditional, modular and house loads relative to their direct energy consumption.
Raised floor energy performance explained

In a raised floor environment the granularity of measurement is reduced, as reflected in the results summary at the end of the report. This is due to the fact that many data center support systems, such as air handler fans, humidification and dehumidification systems, floor-level security, controls, lighting and fire detection/suppression components are shared across large floor areas and customers, whereas in the modular system they are dedicated and metered at the modular level where there may be only a few, or often just a single customer occupant. As a result, calculating PUE for the raised floor is done as a large pool, with input electrical energy measured at the 12,470V backplane infrastructure, with house loads sub-metered and subtracted. Cooling energy is proportioned as described above and additional house loads such as roof-mounted air conditioning systems are proportioned evenly across the building according to proportional square feet and validated with an eQuest simulation of cooling and envelop loads. The energy performance of the raised floor environment is then scaled down to the per-unit level by way of the dimensionless PUE metric.

Phoenix modular environment electrical metering schematic

Figure 5: Simplified electrical hierarchy and metering locations for the traditional raised-floor data center environment.
Results

For the modular environment, analysis was conducted for a "D200" module in 2N configuration, which has 100kVA of available power output for IT and support loads. Based on the analysis of all operating Phoenix modules, IO created a typical operating profile across the different utilization bins. The raised floor environment results are shown at an equivalent scale. Performance results for modular and traditional data center environments are summarized in the tables that follow.

### Annual modular performance (scaled to typical D200 module)

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity @ N</td>
<td>200 kVA</td>
</tr>
<tr>
<td>Redundancy de-rated capacity (@2N)</td>
<td>100 kVA</td>
</tr>
<tr>
<td>Average annual IT power</td>
<td>31.90 kW</td>
</tr>
<tr>
<td>Utilization @ N</td>
<td>16% kW/kVA</td>
</tr>
<tr>
<td>Utilization @ 2N</td>
<td>32% kW/kVA</td>
</tr>
<tr>
<td>IT annual consumption</td>
<td>279,444 kWh</td>
</tr>
<tr>
<td>DMOD energy overhead</td>
<td>15,504 kWh</td>
</tr>
<tr>
<td>Energy input to DMOD</td>
<td>294,948 kWh</td>
</tr>
<tr>
<td>PMOD energy overhead</td>
<td>3,445 kWh</td>
</tr>
<tr>
<td>Energy input to PMOD</td>
<td>298,393 kWh</td>
</tr>
<tr>
<td>Chiller plant energy</td>
<td>68,104 kWh</td>
</tr>
<tr>
<td>Additional overhead for house loads and USS loss</td>
<td>26,714 kWh</td>
</tr>
<tr>
<td>Total energy overhead</td>
<td>113,767 kWh</td>
</tr>
<tr>
<td>Total energy input</td>
<td>393,211 kWh</td>
</tr>
<tr>
<td>Annualized modular PUE</td>
<td>1.407</td>
</tr>
</tbody>
</table>

### Raised floor performance (scaled to equivalent load)

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average annual IT power</td>
<td>31.90 kW</td>
</tr>
<tr>
<td>IT annual consumption</td>
<td>279,444 kWh</td>
</tr>
<tr>
<td>Total energy overhead</td>
<td>204,458 kWh</td>
</tr>
<tr>
<td>Total input power required</td>
<td>483,902 kWh</td>
</tr>
<tr>
<td>Annualized raised floor PUE</td>
<td>1.732</td>
</tr>
</tbody>
</table>

### Energy comparison modular versus traditional

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional energy overhead</td>
<td>204,458 kWh</td>
</tr>
<tr>
<td>Modular energy overhead</td>
<td>113,767 kWh</td>
</tr>
<tr>
<td>Reduction in energy overhead</td>
<td>90,691 kWh</td>
</tr>
<tr>
<td>Percent reduction in energy overhead</td>
<td>44%</td>
</tr>
<tr>
<td>Traditional energy consumption (total input)</td>
<td>483,902 kWh</td>
</tr>
<tr>
<td>Modular energy consumption (total input)</td>
<td>393,211 kWh</td>
</tr>
<tr>
<td>Reduction in total energy input</td>
<td>90,691 kWh</td>
</tr>
<tr>
<td>Percent reduction in total energy input</td>
<td>19%</td>
</tr>
</tbody>
</table>

_Figure 6: Typical energy consumption and efficiency comparison for a D200 data module and the equivalent amount of raised floor space._
To make these results more understandable, IO typically refers to them on a per-MW of IT per year basis. A customer with 1MW of IT load will require 1.73MW of facility power in a traditional raised floor environment versus 1.41MW of facility power in a modular environment. This is a .32MW reduction in power demand. Over the 8,760 hours of a year, the DC2.0 environment saves a customer approximately 2.8 million kWh per MW of IT load. That energy savings has a direct impact on energy cost, water use, and carbon emissions, as described below.

### Results summary and conversion

<table>
<thead>
<tr>
<th>Intensity assumption per kWh</th>
<th>Avoided</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost</strong></td>
<td><strong>$ 0.07</strong></td>
</tr>
<tr>
<td></td>
<td><strong>$ 224,256.00</strong></td>
</tr>
<tr>
<td><strong>Carbon</strong></td>
<td><strong>0.442 kgCO2e</strong></td>
</tr>
<tr>
<td></td>
<td><strong>1,239,014 kgCO2e</strong></td>
</tr>
<tr>
<td><strong>Water</strong></td>
<td><strong>3.15 L</strong></td>
</tr>
<tr>
<td></td>
<td><strong>8,830,080 L</strong></td>
</tr>
</tbody>
</table>
IO’s deployment is a real-world implementation, and these excellent numbers are different than our best-case and design performance—achieved in the face of high-resiliency customer SLAs, in the middle of the desert without free-air cooling, in a Tier III certified/100% uptime data center, and subject to in-depth third party due diligence. The comparative study demonstrated that IO’s modular data center deployment demonstrated 19% energy cost savings and 44% energy waste reduction compared to IO’s traditional raised-floor data center environment.

The underlying components and design of the traditional and modular solution are highly similar. The modules were designed from the ground up, by the same engineers that designed the traditional raised floor, and those modules were created to be a factory-produced, standardized, smaller-scale embodiment of all the same attributes and advantages of the raised floor design.

Energy savings from the study are attributable to a few advantages of the modular design. It is inherently a higher level of airflow containment, with each module housing a much smaller volume of air per server than an open floor. The modularity allows for heterogeneity. A high density modules can sit right next to a low density module and the cooling systems can cater to the requirements of each. In a shared raised floor environment, airflow, temperature and the associated energy required by the cooling equipment, is often dictated by the most stringent design requirement. Last, the modules allow for higher utilization, since capacity can be deployed in an incremental fashion. This allows each system to operate closer to its optimal design condition, even as the data center is still growing.

IO feels as though the resulting numbers of the modular performance are noteworthy, although higher than what is commonly touted in marketing materials. The reason being that real-world deployments quite often fail to achieve best-case operating conditions. Much like how the MPG read-out on your dashboard may or may not equal the performance achieved within the required test conditions for assessing EPA highway and city driving efficiency.

The study achieved its three primary goals, having quantified energy performance between the two environments within IO.Phoenix accurately, demonstrating significant energy, cost, water and carbon savings by the modular technology and controlling for factors such as weather conditions, envelope design, chiller plant efficiency and system utilization to arrive at a performance delta (44% energy overhead reduction) that can be applied as an estimate for the impact of switching to modular technology at other data centers.

Conclusion
Appendix I

A brief description of power usage effectiveness (PUE)

Data centers consume a large amount of electrical power. Not all of the power that enters a data center reaches the information technology equipment (ITE) for productive use. There are losses along the way in the equipment that transform, condition and distribute the power in order to make it suitable for use by the ITE. In typical installations, power also feeds the cooling equipment designed to keep the ITE and other equipment at acceptable operating temperatures. Additional power is used for things such as lighting, security and fire safety systems – essential to a data center, but also not “productive” in the strict sense of the word.

The power that reaches the ITE is productive⁵, and everything else is auxiliary, and a clear place to look for efficiency gains. PUE is used to quantify this efficiency, and it represents total energy input compared to delivered ITE energy.⁶

\[
PUE = \frac{\text{Total facility energy}}{\text{ITE energy}}
\]

A PUE of 2.0 would mean that for every unit of power that reaches the ITE, there is another unit of power that is needed for the support equipment. This is more easily seen by the fact that only two types of power comprise “Total Facility Power” – power that reaches the ITE and power that doesn’t (loss). Substituting, we have:

\[
PUE = \frac{\text{ITE energy} + \text{Overhead energy}}{\text{ITE energy}}
\]

Typically, PUE is measured for entire facilities. As the Green Grid points out, “A mixed-use building may house any number of functions, such as datacenter(s), labs, offices, etc. For these types of mixed-use environments, determining the power usage of just the datacenter environment is difficult. This is particularly true when the utility power grid enters the building through a single entrance point (e.g., through a utility room) and is then distributed to various building locations.”

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⁵ In actuality, not even all of the power that reaches the ITE is productive. There are many opportunities for efficiency from the application layer all the way through the server equipment. For the purposes of PUE analysis, however, what happens downstream of the delivered ITE is not considered.

⁶ Source: Green Grid: PUE™: A COMPREHENSIVE EXAMINATION OF THE METRIC
Further complicating the accuracy of PUE as measured today is the fact that PUE is typically calculated retroactively, looking at energy consumption over a period of time and then calculating an implied average power usage effectiveness over the period.

**Real-time PUE**

In IO's data centers, PUE is measured in real time and available in granularity down to the energy usage of an individual server. The rationale for measuring PUE in this manner is the degree to which it opens the doors for actionable feedback, such as module benchmarking, fault detection, diagnostics and performance information to the user and application writer as well. IO is able to accomplish this new method of PUE calculation for four reasons.

- **Modular design:** IO is leading the industry's transformation into modular data center infrastructure (DC2.0). One of the many benefits of DC2.0 is that systems such as fire suppression, lighting and security, which used to be shared across entire facilities, are now dedicated to individual modules.

- **Measurement:** IO has sensors covering electrical and thermal systems.

- **IO.OS:** IO’s proprietary operating system (IO.OS) is key to unlocking the future of data center infrastructure management. It captures real-time data across the infrastructure monitor, measure and continuously improve.

- **Superior calculation methodology:** IO developed a superior PUE calculation methodology. Appendix II explains that calculation method and its benefits.
Appendix II

IO modular PUE calculation methodology description

The following illustration depicts a simple, dedicated (i.e. systems that are not shared by different users) data center in schematic form. Today, PUE would probably be calculated at the end of a month, quarter or year first by taking total energy consumption (kWh) for the data center and then looking at the measured consumption by the ITE. Component-level losses might be measured directly, but more likely they are the result of educated engineering assumptions.

Above, if 100kW entered as Total Facility Power and 75kW was passed on as IT Equipment Power, then the PUE would be 100kW/75kW = 1.33. Below, we have grouped the same systems in ways that are consistent with the IO modular architecture.

Whether DC2.0 or a traditional data center build out, data centers are rarely as simple as in either illustration above. Modular data centers in the real world look more like the diagram below.

Thanks to the IO.OS, measurements and the resulting PUE are provided in real time, a significant improvement over retroactive measurement since it opens opportunities for monitoring, feedback and continuous improvement. The PUE value is the same as above.

Each PMOD delivers power to (5) DMOD’s, with the chiller plant (CMOD) shared between (2) PMODs and (10) DMODs. The Unit Substation (USS) delivers power to the CMOD and (2) PMODs. A particular customer may only want to know the performance of one of their DMODs, or an individual server. In other instances they may want a PUE for the full deployment.
Calculating PUE the old way, by summing all electrical input and delivered ITE for the entire system and attempting to allocate a portion of that energy to the DMOD of interest might misrepresent the PUE for that module. Even if it were performing at a high efficiency, it might be labeled with a PUE more representative of the system average. Furthermore, in many cases office and other loads that do not directly support the data center may be included in the “Total Input Power” may skew the results.

To calculate PUE on a per-module or even a per-server basis, IO calculates losses on a per-module basis and not in terms of power (total kW) but relative power (kW in/kW out). These are referred to as “burdens” and allow for losses (and PUE) to be calculated in shared systems. That solution is described below. Note that the input values are the same as in the “old way” calculation above and that the PUE result is identical. Furthermore, it does not impact the ability to still calculate full system PUE, or power consumption over time.

“Burdens” and instantaneous PUE

The first step in understanding the real-time system performance is to analyze the performance of the modules involved in delivering the ITE. Losses in those modules present distinct burdens on the platform. From here forward, the term “Burden” will be used to describe a unit-less, instantaneous performance metric.
The **Chiller Module Burden (CMB)** allows for the direct and proportional allocation of chiller module kW usage to each increment of ITE kW usage. None of the CMI directly yields any ITE kW, so all CMI is considered “loss.” Because the chiller module is fed off of the Unit Substation, understanding full chiller module performance also must take into account the losses of the USS associated with the power feed to the chillers.

\[
\text{Chiller Module Burden (CMB)} = \frac{\text{CMI}}{\text{CMO}}
\]

The **Unit Substation Burden (USSB)** reflects the electrical loss in the USS and also allows for proportional allocation of CMB for this electrical loss for each increment of ITE kW usage.

\[
\text{Unit Substation Burden (USSB)} = \frac{\text{USSI}}{\text{USSO}}
\]

The **Power Module Burden (PMB)** reflects the electrical loss in the PMOD and also allows for proportional allocation of CMB for this electrical loss for each increment of ITE kW usage.

\[
\text{Power Module Burden (PMB)} = \frac{\text{PMI}}{\text{PMO}}
\]

The **Data Module Burden (DMB)** reflects the electrical loss in the DMOD and also allows for proportional allocation of CMB for this electrical loss for each increment of ITE kW usage.

\[
\text{Data Module Burden (DMB)} = \frac{\text{DMI}}{\text{DMO}}
\]
Calculating total loss factor

The Total Loss Factor turns distinct burdens into a single term that describes losses in the system, per kW of ITE power. The total loss factor calculation involves three components.

- It must include inefficiency along the power path.
- It must include losses to the cooling system to cool all of the power on the power path.
- It must include losses to the cooling system to cool the power system losses associated with the cooling system itself.

Each component is defined below.

Power path requirement

This term is the product of all electrical path burdens and the ITE, which equals:

\[ IT \times (DMB \times PMB \times USSB) \]

If no cooling plant were required, this would equal Total Power Input and dividing by ITE would yield the PUE.

Cooling burden requirement

The cooling system takes power and produces “heat removal capability” like an energy conveyor. All of the power that enters the cooling system is loss, since none of that power ends up reaching the ITE for use. The cooling system requirement is the product of the chiller plant performance burden and the total power path requirement:

\[ (CMB) \times (ITE \times DMB \times PMB \times USSB) \]

Adding this to the Power Path Requirement from part 1 and simplifying yields the numerator of the Total Input Power equation shown at the bottom of the next page:

\[ ITE \times ((DMB \times PMB \times USSB) \times (CMB+1)) \]

The expression above is equal to the total input energy required per unit of IT energy. Dividing by ITE itself results in PUE.

\[ PUE= \frac{ITE \times ((DMB \times PMB \times USSB) \times (CMB+1))}{ITE} \]

\[ PUE= (DMB \times PMB \times USSB) \times (CMB+1) \]
Appendix III

Glossary of terms

**Backplane:** Critical data center infrastructure electrically “upstream” of the UPS system.

**Burden:** a unit-less, instantaneous performance metric.

**CMB:** Chiller Module Burden. The portion of cooling kW associated with each kW of ITE.

**CMI:** Chiller Module Input. The power in kW entering the chiller module.

**CMO:** Chiller Module Output – Heat Rejection Capacity. Cooling Capacity in kW delivered by the chiller module.

**CMOD:** Chiller Module or Chiller Plant. A group of equipment typically consisting of chillers, pumps and cooling towers.

**CUE:** Carbon Usage Effectiveness. Defined by The Green Grid and expressed in units of kg CO2e/ kWh IT.

**DC1.0:** A construction-built raised-floor IT environment.

**DC2.0:** A factory-produced modular data center environment with integrated Data Center Infrastructure Management software.

**DCIM:** Data Center Infrastructure Management. A software system to provide visibility and control for the data center.

**DMB:** Data Module Burden. The portion of electrical loss associated with each kW of ITE.

**DMI:** Data Module Input. The power in kW entering the DMOD.

**DMOD:** Data Module. A module housing the ITE, typically consisting of PDU’s and cooling infrastructure.

**EUE:** Energy Usage Effectiveness. Similar to Power Usage Effectiveness, but calculated over time rather than instantaneously.

**ITE:** Information Technology Equipment.

**kW:** Kilo Watt, a unit of power.

**kWh:** Kilo Watt Hours, a unit of energy.

**PDU:** Power Distribution Unit.

**PMB:** Power Module Burden. The portion of electrical loss associated with each kW of ITE.

**PMI:** Power Module Input. The power in kW entering the PMOD on the input bus.

**PMO:** Power Module Output. The power in kW leaving the PMOD critical bus.

**PMOD:** Power Module. A module consisting of power conditioning equipment, typically a switchboard, UPS, backup storage and cooling infrastructure.

**PUE:** Power Usage Effectiveness. A metric defined by The Green Grid and expressed in units of kW IN/kW to IT.

**$UE:** Dollar Usage Effectiveness. A metric used by IO that combines PUE and the local utility rate. Expressed in terms of $/kWh to IT.

**UPS:** Uninterruptible Power Supply.

**USS:** Unit Substation. Electrical equipment housing transformer, distribution panel and switchgear.

**USSB:** Unit Substation Burden. Ratio of input divided by output at the Unit Substation.

**WUE:** Water Usage Effectiveness. Defined by The Green Grid and expressed in terms of Liters H20/kWh IT.
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If you have any questions about this study or technical paper, please contact IO’s sustainability department via email at sustainability@io.com.

References


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