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PUE Calculations:
The Model and the Myths

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This **White Paper** explores some of the more common Power Usage Effectiveness (PUE) calculation mistakes and myths while demonstrating their impact on PUE values calculated for a specific data center facility design project.

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Introduction

It is unfortunate that an acronym as widely used in the data center industry as "PUE" is most often misused. Few will argue that energy efficiency is an important metric in the operational analysis of a data center facility. However, *Power Usage Effectiveness*, commonly referred to as *PUE* has become more of a marketing tool than an energy efficiency metric. This exploitation is particularly blatant in the marketing of new data center design "innovations". This paper explores some of the more common PUE calculation mistakes and myths while demonstrating their impact on PUE values calculated for a specific data center facility design project.

PUE Calculation Model

Defining PUE

Elementary to an examination of *Power Usage Effectiveness* (PUE) calculations is an understanding of industry definitions for the various PUE Categories. There are four such recognized Categories, labeled PUE 0, PUE 1, PUE 2 and PUE 3. All four Categories are similar in that they examine the ratio of *Total Data Center Facility Energy* to (Critical) *IT Energy*.

$$PUE = \frac{Total\ Data\ Center\ Facility\ Energy}{IT\ Energy}$$

All four PUE Categories require that the *Total Data Center Facility Energy* reflect all energy sources serving both the data center and supporting ancillary spaces. However, the Categories quantify *IT Energy* quite differently with respect to the location of measurement. The table below provides a summary of *Energy* elements used in the four PUE Category calculations recognized by industry.

PUE ENERGY ELEMENTS				
	PUE Category 0	**PUE Category 1**	**PUE Category 2**	**PUE Category 3**
IT Energy	• Instantaneous peak kW demand • Measured at UPS output	• Total annualized kWh consumption • Measured at UPS output	• Total annualized kWh consumption • Measured at PDU output	• Total annualized kWh consumption • Measured at IT input
Total Data Center Facility Energy	• Instantaneous peak kW demand • Measured at facility input	• Total annualized kWh consumption • Measured at facility input	• Total annualized kWh consumption • Measured at facility input	• Total annualized kWh consumption • Measured at facility input

Note that PUE 0 actually references *Power* (defined as the *rate at which Energy is consumed*.) Whereas PUE 1, PUE 2, and PUE 3 reference *Energy* (defined as the *amount of Power consumed*.)

As an instantaneous peak measurement of what is essentially the *worst case* PUE for a facility, the calculation of PUE 0 should be fairly straight forward for both existing and theoretical data centers. Unfortunately, many people boast a PUE value that represents the minimum instantaneous PUE; one that measures power (kW) under ideal conditions at the most energy efficient operating point. This does not reflect real-world conditions and is more appropriately defined as a *Fantasy PUE* which is not recognized by any accepted industry standard.

Calculations for PUE 1, 2, and 3 require an analysis of energy consumption as it varies throughout the year. In an existing operational facility, this is well defined as actual real-time measured energy; with *Total Facility Energy* measured at the Facility boundary (or utility feed entry) and *IT Energy* measured at the respective PUE Category's source point. However, the calculation of theoretical PUE for a proposed facility has yet to be clearly defined by industry. This is particularly noticeable with respect to procedures for applying weather data, establishing appropriate IT equipment load levels, and estimating the energy consumed by ancillary systems.

Modeling PUE

To demonstrate the impact of PUE calculation abuses, detailed PUE calculations for an actual data center design project (Project X) were modeled. Project X comprised a nominal 200,000sf data center facility with approximately 130,000sf of computer room space designed for a nominal 26,500 kW peak critical design load. The facility's power and cooling requirements were accommodated by a rotary UPS system and a high temperature chilled water system. Similar to most dedicated data centers, the facility also included space for Operations and Facility Support Services.

The energy elements used in the calculations can be generally summarized as follows:

- Critical power
- Central chiller plant cooling system
- Data center cooling fans
- UPS losses
- UPS cooling fans
- Switchgear and distribution losses
- Data center ventilation and humidification systems
- Support services ventilation, cooling and heating systems
- Miscellaneous electrical
- Miscellaneous non-electrical (gas)

As dictated by industry standards, all energy elements (inclusive of non-electrical energy) associated with the *Total Data Center Facility* were included in the analysis. Natural gas consumed by the boilers supporting the heating water system was accounted for by converting Mbh to kW and applying an industry-defined 0.31 weighting factor. As demonstrated in the dissemination of the following PUE Myths, ignoring some or all of these, often over looked, energy elements will have a noticeable impact on calculated PUE values.

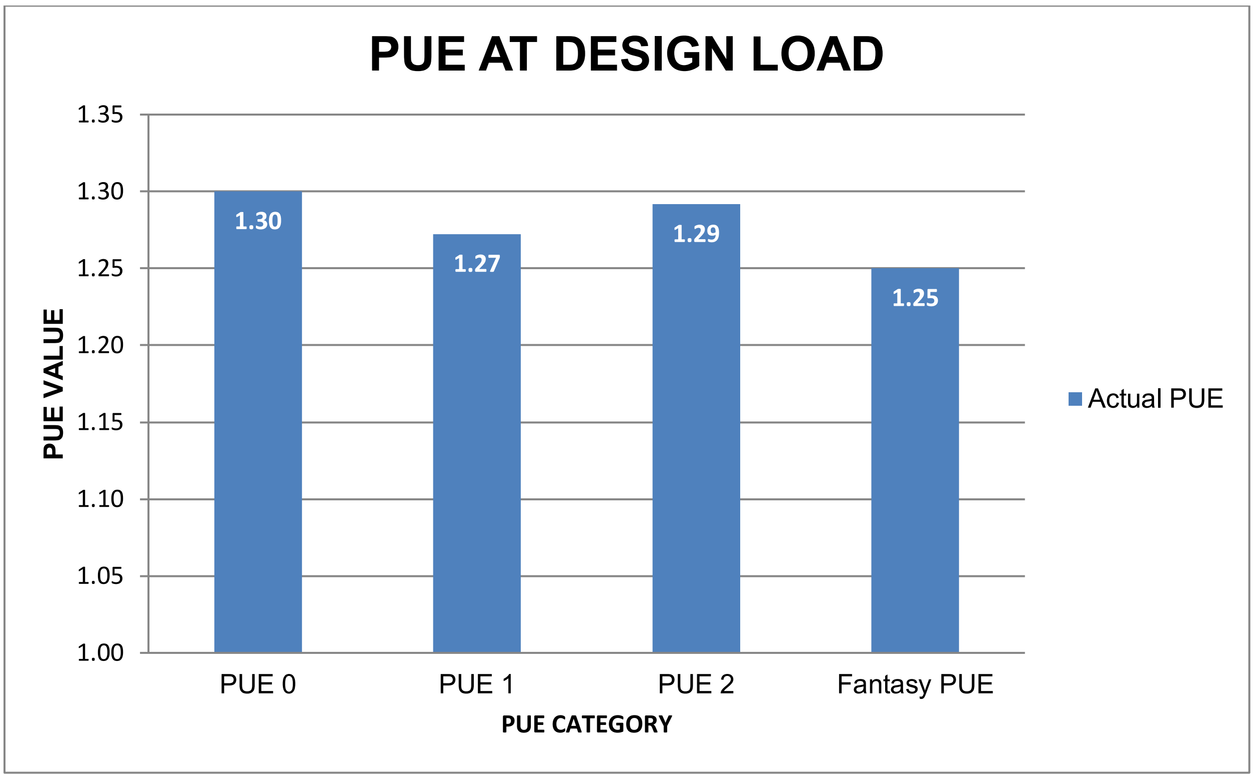
Weather data for Project X was obtained from Typical Meteorological Year services and segmented into two-degree temperature bins. This temperature profile, along with facility design data and manufacturer's actual part load equipment efficiency data were used to develop detailed calculations for each PUE Category under varying critical IT load conditions.

PUE Calculation Myths

Myth 1: All PUEs are created equally

Even when calculated properly to obtain *Actual PUE*, PUE values vary significantly between Categories. The chart below summarizes the results of the various PUE calculations at peak loading for Project X. Note that PUE 3 values (where critical load is measured at IT input) has not been included in the chart because the electrical distribution losses between PDUs and IT equipment were insignificant for this project. This rendered PUE 3 values equivalent to PUE 2 values (where critical load is measured at PDU output). Also note that, given its prevalent misuse in the industry, the aforementioned *Fantasy PUE* value has been included for reference in this and subsequent charts.

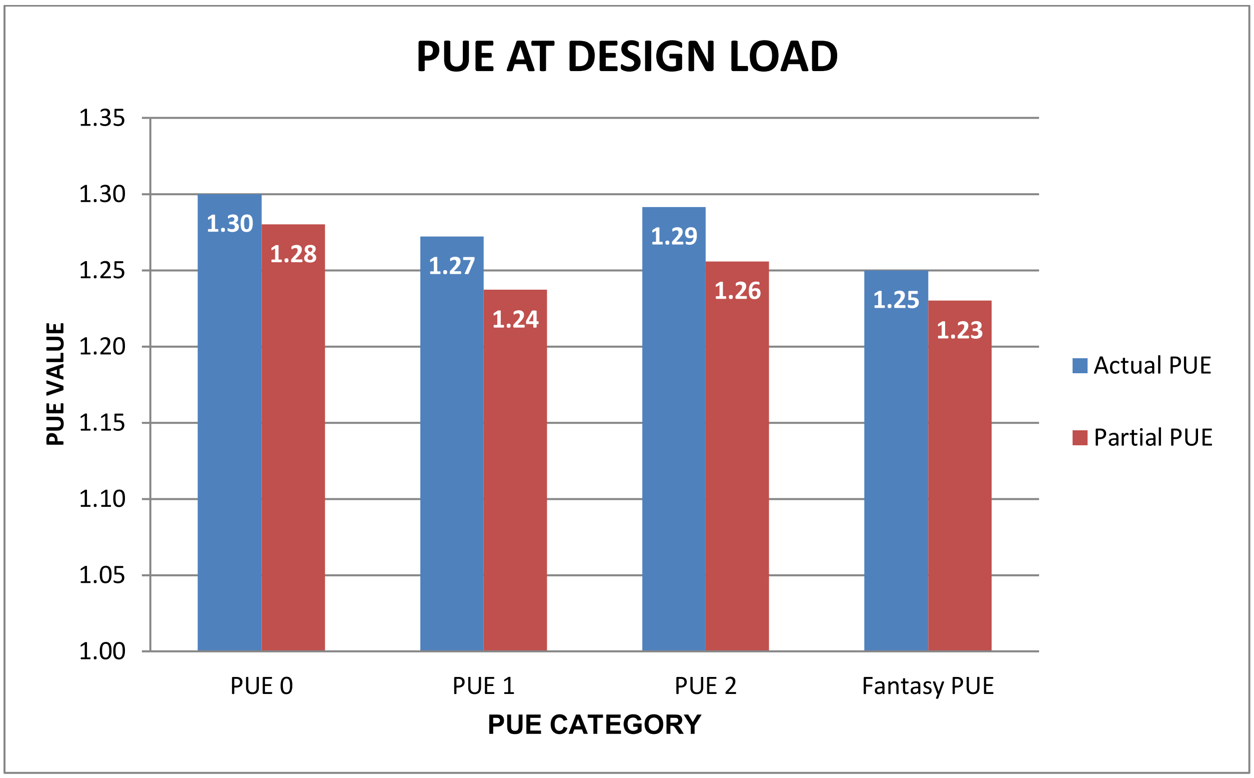
As illustrated in the chart below, annualized *Actual PUE* values for Project X varied by up to 0.05, with instantaneous *PUE 0* having the highest value and instantaneous *Fantasy PUE* having the lowest value.



Myth 2: Power for ancillary data center systems can be ignored in PUE calculations
Perhaps the most blatant yet fairly common abuse in calculating PUE is the omission of energy used by ancillary data center systems, particularly if some are shared by the data center in a mixed-use facility. The following ancillary systems were included in the PUE calculations for Project X, which was a dedicated data center, and are listed in order of descending annualized power consumption.

- Building lighting
- UPS cooling fans
- Switchgear and distribution losses
- Data center humidification
- Data center ventilation fans
- Support services cooling fans
- Data center ventilation, gas heating
- Miscellaneous power
- Support services gas heating
- Support services electric heating
- Central heating water system pumps
- Toilet and utility ventilation fans

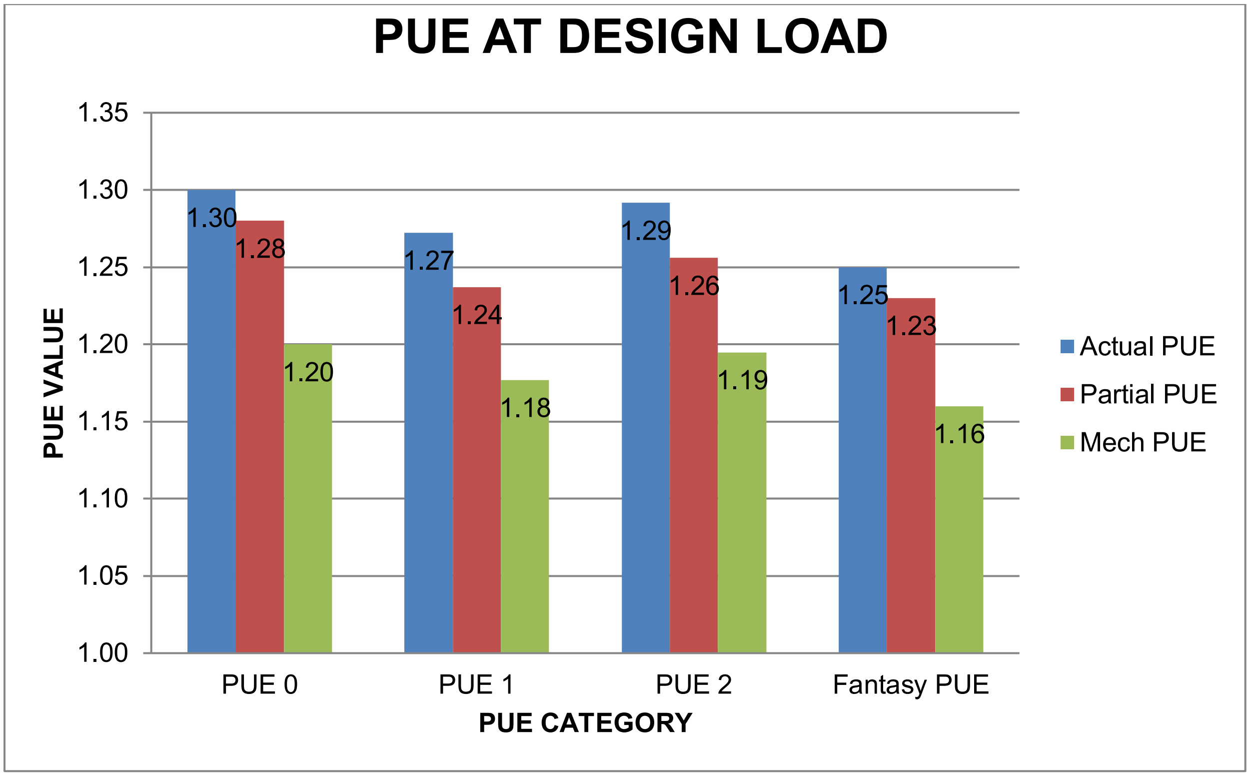
These annualized loads remained fairly constant relative to the critical design load. Combined, they represented 1.41% of the total annual energy for Project X when operating at design load. The resulting *Partial PUE* values obtained when these ancillary loads are ignored, although often quoted, are not recognized by industry standards. As shown in the following chart, these *Partial PUE* values improve upon their *Actual PUE* counterparts by up to 0.03.



Myth 3: UPS losses can be ignored in PUE calculations

In an attempt to illustrate mechanical cooling system efficiency, PUE values are often calculated with the exclusion of UPS losses. Needless to say, when UPS losses are ignored, energy used by ancillary systems also tends to be forgotten. By omitting these major components of consumed data center energy, the resulting PUE values are unrealistically low. These resulting *Mechanical PUE* values only comprise two energy components; critical IT load energy and data center cooling energy (hopefully inclusive of both central systems and local fan energy). As with *Partial PUE* values, there is no industry recognition of *Mechanical PUE* values.

UPS losses in Project X accounted for only about 4% of the total power at design load. However, as shown in the chart below, ignoring these UPS losses (along with ancillary systems energy) resulted in *Mechanical PUE* values reflecting a 0.09 to 0.10 improvement over *Actual PUE* values.



Myth 4: PUE is a prediction of energy performance (Corollary: Critical loading doesn't matter)

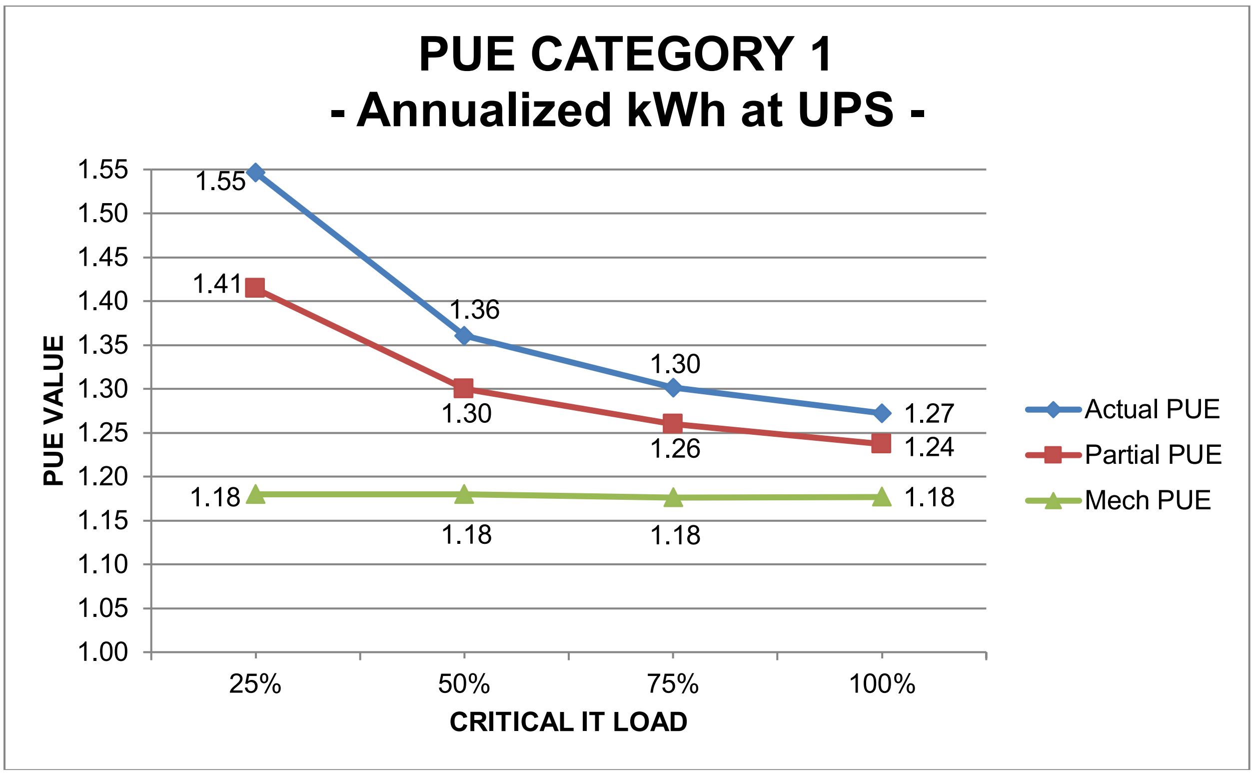
Even when calculated in strict accordance with industry standards, PUE cannot accurately predict energy performance. This is due primarily to generally volatile variations in loading of the critical IT systems. As the critical load drops below design, many of the components comprising *Total Data Center Facility Energy* remain relatively constant. This results in increased PUE values across all Categories.

The largest factor in these components is UPS losses. In response to the growing data center industry, that typically employs multiple UPS modules operating at part load (for redundancy), UPS manufacturers have developed systems that are optimized within a loading range of about 40-70%. However, even these state-of-the art UPS systems, with optimum efficiencies at 95% or better, tend to lose efficiency as their loading decreases. This results in UPS losses that are a higher relative component in *Total Data Center Facility Energy* as the critical load falls below peak design. For Project X, the UPS losses represented about 4% of *Total Facility Energy* at peak critical load, but almost 8% when the critical load dropped to 50% of design, even with the UPS systems still operating within their peak efficiency range. At 25% critical load the UPS systems were operating at only 21%, which was well below their optimum range. This resulted in UPS losses that comprised more than 13% of *Total Facility Energy*.

Ancillary energy components also contribute to this imbalance as the IT load falls, but to a lesser extent. For Project X, they represented about 1.4% of the *Total Facility Power* at peak critical load, rising to about 4.5% with the critical load at 25% of design.

The resulting impact of varying IT loading on PUE values can be significant and should be a primary concern, particularly at initial occupancy of a data center when the critical load is often well below design capacity. Facility operators are then shocked to see actual measured PUE values much higher than promised predictions, particularly if these predictions were based on *Partial* or *Mechanical PUE* calculations.

Since this phenomenon affects all PUE Categories similarly, only PUE Category 1 values relative to critical loading have been presented in the graph below. Note that the promising *Actual PUE* of 1.27 at 100% of the critical IT design load rises to the more modest 1.36 when the IT load is at 50% of design and to a disappointing 1.55 at 25% of critical load.



Myth 5: Alternative and Renewable energy sources can be ignored in PUE calculations

It cannot be overemphasized that PUE is intended to demonstrate energy efficiency *within* a data center facility. Natural gas, fuel oil, district water or steam, and other non-electric energy sources must be included in all valid PUE calculations. Once converted to kWh, an established weighting factor should be applied to account for each of these *Alternative Energy* sources as *Equivalent kWh* (as illustrated in the equation below) in the summation of *Total Data Center Facility Energy*.

$$Equivalent\ kWh = Alternative\ Energy\ kWh \times kWh\ Weighting\ Factor$$

The following table summarizes weighting factors established by industry for common alternative energy sources utilized by data center facilities.

Alternative Energy Source	kWh Weighting Factor
Natural Gas	0.31
Fuel Oil	0.30
Other Fuels	0.30
District Chilled Water	0.31
District Hot Water	0.40
District Steam	0.43
Condenser Water	0.03

Likewise, any renewable electrical energy generated outside the data center facility boundary and used *within* the facility must be included in the PUE calculations as raw electricity. Thus, the use of solar or wind energy may be considered "green", but their use does not have any effect on the PUE values of the data center facility.

Ultimate Myth: A PUE of less than 1.0 is realistic and should be a design goal

Although an ambitious target, a PUE of 1.0 or less is simply not attainable. Properly calculated, a PUE of 1.0 would require 100% efficiency of all power systems, which means no electrical losses of any kind. It would also require that no energy be consumed for cooling, ventilation, humidification, water, security, lighting, and any other electrically powered systems associated with the data center. The more outrageous PUE of less than 1.0 violates the first law of thermodynamics as it would require the creation of energy from nothing.

Anyone claiming a PUE in any of the four recognized Categories that is less than or equal to 1.0 has not calculated that PUE in accordance with established industry standards.

Conclusion

As demonstrated with the Project X model, quoted PUE for a given project can vary significantly (by 0.43 for Project X) depending on the critical system loading and the calculation method employed. Lacking the numeric suffix that delineates PUE Category (i.e. PUE **0**, PUE **1**, PUE **2**, or PUE **3**) there is simply no way to know if a presented PUE value complies (at least in intent) with established calculation protocols. To normalize properly Categorized PUE values for comparison, system details such as IT loading, weather data, and applicable ancillary systems should also be published. Once properly categorized and normalized, comparison of like PUE Categories can then be a useful tool in the comparison of alternative data center power and cooling systems during the design process.