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INFRASTRUCTURE USAGE EFFECTIVENESS (IUE™)

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Executive Summary

The Green Gauge Standard Committee, CCSA (TGGC) — a Chinese nonprofit consortium with a mission to promote ideas, standards, and best practices for green data centers to achieve sustainability and social responsibility — proposes a new metric, called Infrastructure Usage Effectiveness or simply IUE™. This metric addresses one of the most important challenges that data center owners face: how to utilize infrastructure resources effectively so as to minimize operational risks, maximize the use of available resources, and avoid building or leasing new facilities while leaving significant resources stranded. IUE™ gives data center owners and managers an effective way to assess infrastructure resource usage efficiency, identify design and operational deficiencies, and guide improvements in the use of infrastructure resources to improve TCO as well as reliability and availability.

IUE™ in its current form includes five (5) infrastructure resource elements. On one hand, the authors recognize that these five elements are not inclusive; there are other important elements that some data center owners value. We will work with industry experts to identify and include them into IUE™. On the other hand, the authors realize the usage complexity with that many elements. As a comparison, PUE™ is easy to understand and simple to use with only two elements; total energy use by a data center and energy use by IT equipment. The authors encourage industry experts and early adopters to work on their own or with the authors to establish guidelines or build online tools to help reduce barriers and complexity for using IUE™ and enable wide adoption of the metric to benefit the entire data center industry.

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I. Introduction

If you cannot measure, you cannot improve. Key metrics can help data center owners improve resource usage efficiency, reduce total cost of ownership (TCO), and enhance environmental responsibilities. When implemented properly, all these goals can be achieved while maintaining or improving data center availability.

Since 2007, The Green Grid Association has produced several xUE metrics dealing with data center resource usage efficiency issues. The Power Usage Effectiveness (PUE™) metric has proven to be a valuable industry tool for measuring data center energy usage efficiency. Today, data centers around the world do not start the discussion on energy usage efficiency without using PUE™. The Carbon Usage Effectiveness (CUE™), Water Usage Effectiveness (WUE™) and Space Usage Effectiveness (SpUE™) metrics are all gaining traction among data center owners. This series of xUE metrics is helping the data center community grow and evolve more efficiently.

However, data centers require more than power, water and space. Infrastructure resources, such as power infrastructure and cooling infrastructure, are of great importance and critical to successful operation and CapEx hungry. Consequently, performance and availability of infrastructure resources can significantly impact business survival and growth.

The world is witnessing a data explosion, and with it, a high demand for more data centers. New data centers, especially hyperscale data centers, can cost hundreds of millions or even billions of dollars in capital expenses (CapEx), while outsourcing can cost a substantial amount in monthly operational expenses (OpEx). Before deciding on building new data centers or lease, decision makers should first ask a critical question: How efficiently the existing facilities are being used, and is the conclusion that business needs outgrow existing facilities perceived or real? Too often, the real problem behind claimed shortage of data center facilities with respect to meeting digital growth is the mismanagement of infrastructure resource usage. To better equip the decision makers with tools to reach sensible decisions that can potentially hinder or promote business growth, proper metrics will be needed. After all, if you cannot measure, you cannot improve.

TGGC believes that IUE™, along with other xUE's, can help data center owners and operators manage their resources more effectively, enhance their competitiveness, while meeting their social responsibility requirements.

II. Infrastructure Usage Effectiveness (IUE™)

To sustain IT operation, infrastructure resource capacities must be available and sufficient. For instance, to support 100kW IT load, there must be sufficient power (≥ 100kW) capacity, sufficient cooling (≥ 100kW) capacity, and sufficient number of racks and U slots to house servers. Power, cooling, rack space, etc. are all considered infrastructure resources required to support IT load.

Ideally, all infrastructure resource capacities are consumed at the same rate as IT load. When 60% of IT load is deployed, 60% of all infrastructure resource elements are consumed. As IT load increases, usage of infrastructure resource elements increases too, at the same pace. When IT load usage reaches 100%, so do resource elements. This scenario represents the most efficient data center design/operation with full utilization of all infrastructure resources.

In the real world, inefficiencies in infrastructure resource usage is inevitable due to design and operational constraints and/or flaws. Usage inefficiencies are manifested in the form of discrepancies between IT load usage and infrastructure resource usages, and more specifically in the form of consumption of one or more resource elements at rates faster than that of IT load. For instance, when 60% of IT load is deployed, usage of one particular infrastructure resource element may hit 80% or even higher. This usage discrepancy renders this data center less useful than the design goal; meaning IT load will not be able to expand to 100% of design capacity because at least one resource element will have insufficient capacity to support an IT load beyond perhaps 70% or 80%.

Infrastructure Usage Effectiveness (IUE™) is designed to assess and identify resource usage inefficiencies with reference to IT load.

NOMENCLUTURE

1. Cooling in this white paper refers to processes of removing heat generated by IT components and devices and ultimately releasing the heat into the outside environment; the atmosphere.
2. Mechanical Cooling refers to processes using compressors to generate cooling capacity needed for heat removal via electromechanical means including, but not limited to, chillers and direct expansion systems.
3. Free Cooling refers to processes that extract cooling capacity available in the environment; i.e. the ambient air for heat removal when dry bulb and/or wet bulb temperatures are favorable.

   a. Direct Air Economization – A type of Free Cooling process that draws fresh air, mixes with exhaust air and/or add moisture when necessary to provide cooling air to IT equipment
   b. Free Cooling other than Direct Air Economization – Processes involving heat exchangers of some sort, including but not limited to Indirect Air Economization and Waterside Economization
   c. 100% Free Cooling refers to data center cooling processes where heat removal relies entirely on Free Cooling without making use of any mechanical compressors
   d. Partial Free Cooling refers to data center cooling processes where heat removal is accomplished via the combination of Free Cooling and Mechanical Cooling.
4. Air Cooling refers to cooling processes that remove heat generated by IT devices with air as a cooling medium. In Air Cooling, cooling air is forced, by air moving devices such as fans and blowers, to flow past heat generating IT devices, absorbing heat in the process and being collected and dumped to the atmosphere.
5. Cooling Air Delivery refers to the mechanisms that deliver cooling air to IT cabinets; i.e. the heat sources. They include cooling systems placed at the perimeter of the room, in-row amongst IT racks, overhead or in-rack.
6. Liquid Cooling refers to cooling processes that remove heat generated by IT devices with liquids as cooling media. It includes processes where
   a. A cooling liquid is brought directly to the heat sources, such as a CPU either directly in contact with the heat sources (such as immersion liquid cooling), or indirectly (such as cold plates)
   b. A cooling liquid is brought to individual cabinets within which IT equipment such as serves and network equipment are housed with the cooling liquid being physically far removed from heat sources (such as liquid cooled cabinet doors).
7. Both Air Cooling and Liquid Cooling can involve Mechanical Cooling, Free Cooling, or a combination of Mechanical Cooling and Free Cooling.
8. CRAC refers to Computer Room Air Conditioning units that include compressors.
9. CRAH refers Computer Room Air Handler units that deliver cooling air to IT equipment by blowing air over cooling coils filled with chilled water supplied by Chillers.
10. UPS refers to Uninterrupted Power Supply systems.
11. Utility refers Utility power typically connected to utility grid.
12. RPP refers to Remote Power Panel, wall mount or floor mount units.
13. PDU refers to Power Distribution Units, wall mount or floor mount units.

DEFINITION

Infrastructure Usage Effectiveness (IUE™) of any resource element is defined as a ratio between (1) what is consumed and (2) what is available as the design capacity.

$$\text{Usage} = \frac{Consumed}{Capacity}$$

INFRASTRUCTURE RESOURCE ELEMENTS

The intent of this White Paper is to cover a few selected and important infrastructure resource elements based on a principle that a metric needs to be simple enough to understand and to apply. The infrastructure resource elements that are covered in the current version of IUE™ are not inclusive; there are other elements that can be potentially important to some data center owners and can be added to IUE™ to cover a broader base of DC infrastructure resources. The authors leave the options open for inclusion of other infrastructure resource elements for IUE™ discussions in the future and encourage the industry experts to work together to expand and modify IUE™ with the goal of improving data center resource efficiency.

Data center Infrastructure, presented in the current White Paper, will cover the following five (5) resource elements:

1. Power Delivery
2. Power Distribution
3. Cooling Generation
4. Cooling Flow
5. Rack U Count

A brief description of how these five resource elements are related to IT Load and applicability of each resource in the IUE™ discussion is shown in the table below. These relationships will be explained in full details in the following sections.

Resource	Relationship to IT Load	Applicability
Power Delivery	Phase balance at UPS's or any other means providing power to the IT equipment such as, but not	Applicable to all situations – - Mechanical Cooling - Free Cooling/Direct Air Economization

	limited to, fuel cell with direct connection to IT, or Utility to which IT Load is directly connected.	- Free Cooling/all other forms - Air Cooling - Liquid Cooling - Hybrid Mechanical-Free cooling - Hybrid Air-Liquid cooling.
Power Distribution	Distribution of power to IT Load by RPP's or PDU's via different connectivity (e.g. phase-phase or 3-phase).	Applicable to all situations.
Cooling Generation	Operating conditions of Mechanical Cooling systems, and Free Cooling (except for Direct Air Economization) systems.	Applicable to all situations except for Free Cooling/Direct Air Economization.
Cooling Flow	For Air Cooling, IT equipment cooling air requirements and leakage through containment. For Liquid Cooling, IT equipment cooling liquid requirements.	Applicable to all situations except for: • Air Cooling where cooling airflow delivered to IT equipment is accomplished by air-moving devices that are not a part of infrastructure resources (e.g. cooling airflow is driven only by fans that are part of IT equipment or IT racks) • Cooling systems employ fixed fan drives @ 100% duty all the time.
Rack U Count	IT equipment power density	Applicable to all situations.

III. Infrastructure Resource Elements – Capacities

This section covers the **Capacity** portion of the usage definition (= Consumed / **Capacity**).

Infrastructure Resource Elements – **Capacity**

1. Power Delivery Capacity – A measure of available power that IT Load can draw on
   a. Power Delivery Capacity = UPS output capacity (in kW) or any other means providing power to IT equipment such as, but not limited to, fuel cell technologies and other future power delivery technologies
   b. Power Factor (PF), given modern IT equipment all have PF close to unity, can be treated as if all IT equipment come with PF=1.0. As such, only kW is discussed in this White Paper

   c. Power Delivery Capacity efficiency is covered by PUE™ discussions and has no impact on UPS output capacity. As a result, UPS efficiency is not a part of IUE™ discussions
   d. In the case of direct connection of IT Load to utility power, Power Delivery Capacity = Utility capacity (in kW).

2. Power Distribution Capacity – A measure of available circuit breakers to which IT Load/Equipment can be connected
   a. Power Distribution Capacity = Number of poles or circuit breakers designed to support IT equipment racks
   b. The output power from UPS is fed to IT equipment via PDU's or RPP's
   c. PDU's or RPP's contain panel boards with fixed number of poles, each connected to a circuit breaker
   d. For a given data center power requirement, planned rack densities and rack U count, and anticipated future plans, the number of panel boards and pole positions are defined and fixed per rack row, per rack containment (including a pair of rack rows), and the entire data hall (with multiple containment units).

3. Cooling Generation Capacity – A measure of available cooling capacity
   a. Cooling Generation Capacity = The total capacity of cooling generation at a specific operating condition at the time of assessment
      i. Cooling Generation is excluded for Direct Air Economization
      ii. This assessed capacity may be different from Manufacturers' advertised Cooling Generation capacity if the operating conditions are different
   b. In a Chiller-CRAH scheme, both the Chillers and the CRAH units have separate cooling capacities. Since it is not uncommon that overall cooling capacity for the CRAH units based on Manufacturers' standard value is greater than that for the Chillers per Manufacturers' advertised value, the overall cooling capacity available for a data center can only be determined by the smaller of the two cooling capacities
   c. In cases where cooling involves hybrid Air/Liquid Cooling, separate the capacities for Air Cooling and Liquid Cooling since capacity and usage of each could be a limiting factor for the facility.

4. Cooling Flow Capacity – A measure of available cooling flow that can sustain IT Load/Equipment to within specified operating temperature range

   a. For Air Cooling, Cooling Flow Capacity = Cooling air flowrate capacity (in m3/hour or CFM) by fans/blowers in (i) CRAC/CRAH units, or (ii) fan walls
   b. For Liquid Cooling, Cooling Flow Capacity = Cooling liquid flowrate capacity (in gallons/min or m^3/sec).

5. Rack U Count Capacity = Total # of installable rack U space in a data hall (total number available U slots)
   a. In modern data centers where aisle containment is deployed, number of deployable IT racks is defined and fixed. Further, U space in each rack is determined as well; 42U available U slots for a 42U rack
   b. In legacy data centers or those where aisle containment is not deployed, there are several factors that may affect the number of deployable IT racks. There may be some flexibility in the widths of cold aisle, hot aisle, or service corridors. Nonetheless, the minimum aisle width requirements more or less limit the variability of number of deployable IT racks in a given white space.

IV. Infrastructure Resource Elements – Consumed

This section covers the **Consumed** portion of the usage definition (= **Consumed** / Capacity)

To operate, IT equipment will **demand** resources including power, cooling and space. For instance, a server can demand 500 watts of power and cooling and 2U space in an IT rack. To sustain IT operation, infrastructure resources must be available to be **consumed**. Depending on resource types and design and/or operation efficiencies, **demand** and **consumed** may or may not be the same.

Infrastructure Resource Elements – **Consumed**:

1. Power Delivery Consumed
   a. Power demand by IT equipment is expressed in watts. In data centers, 3-phase power is provided to IT equipment. Some IT equipment are connected to all 3 phases, and others to one phase or phase-phase. But in aggregate, all IT equipment in a data center draw power from all 3 phases
   b. Depending on IT equipment design, planning and connectivity, an imbalance in current draws in 3 phases can occur. The severity of current imbalance and/or the lack of connection flexibility in IT equipment can cause one phase to be loaded more heavily

than other phases, resulting in one or more phases still have capacity available but un-usable. When this happens, the consumed power at UPS's or utility sources (when IT Load is directly connected to utility sources) becomes higher than the demand power by IT Load

   c. The consumed power of UPS is calculated as follows:
      i. The maximum phase current, I_{max} among all 3 phases
      ii. Calculate UPS consumed power based on I_{max} and nominal Voltage
      iii. In a well-balanced system, loads on all three phases in a UPS system are similar. Here demand (by IT equipment) ≈ consumed (by UPS).

2. Power Distribution Consumed
   a. Power Distribution Consumed = number of poles or circuit breakers on PDU or RPP used by IT equipment racks
   b. Use of single phase or phase to phase (2 poles) vs. 3-phase can be a source of inefficiency as they may use more poles for a given power
      i. For instance, in a typical North America 208VAC 3 phase-4 wire system, to power an 8kW rack with 30A services, a phase to phase connection will result in use of 4 poles[1] while a 3-phase connection will use 3 poles.

3. Cooling Generation Consumed
   a. For single mode cooling, i.e. 100% Mechanical Cooling or 100% Free Cooling that does not involve Direct Air Economization, Cooling Generation Consumed = IT Load + other DC heat load (e.g. lighting, etc.).
   b. Cooling Generation Consumed can also be measured and calculated based on data available from cooling systems, Mechanical Cooling or Free Cooling (excluding Direct Air Economization)

4. Cooling Flow Consumed
   a. For Air Cooling, Cooling Flow Consumed = Total cooling air in m^3/hour or CFM supplied by data center cooling system fans/blowers to maintain specified environmental conditions
   b. For Liquid Cooling, Cooling Flow consumed = total liquid flow in gallons/min or m^3/sec supplied by the data center systems.

[1] 8 kW load at 208V single phase draws 38.5A. A 30A 2 pole circuit breaker can only support 24A of continuous load, therefore to serve this rack two (2) 30A, 2 pole breakers would be required. Whereas, the same 8 kW rack would draw 22.2A at 208V three phase and can be served from a single 30A, 3 pole circuit breaker.

5. Rack U Count Consumed
    a. Rack U Count Consumed = Quantity of U's occupied by IT equipment across all installable racks and U slots.

V. Calculating IUE™

Step 1 – Measure baseline IT load in kW

a. Efforts should be made to measure IT load as close to IT racks as possible, i.e. at rack PDU's. The summation of all rack level power measurements is the data center IT load
b. It is also acceptable to take up-stream measurements, e.g. at row level or at room level or UPS level as IT load measurements
c. IT Load usage = Measured IT Load / IT Capacity.

Step 2 – Determine what Infrastructure Resource Elements to include in the IUE™ considerations

a. Out of 5 elements discussed in the previous sections, users can choose any number of elements either out of necessity (e.g. an 100% adiabatically cooled data center will exclude Cooling Generation consideration) or out of choice (e.g. one or more elements may not be important to a data center owner for any reasons at a given moment).

Step 3 – Gather specification sheets from equipment vendors to determine resource capacities. Remember redundant capacities should not be double-counted

a. In a 1+1 power delivery scheme with UPS rated at 1,000 kW, Power Delivery capacity = 2 x 50% x 1,000 kW = 1,000 kW
b. In an 8+2 cooling generation scheme with CRAC rated at 100 kW each, Cooling Generation capacity = 8 x 100 kW = 800 kW
c. Cooling Generation capacity must be accounted for for all cooling mechanisms except for Free Cooling/Direct Air Economization.

Step 4 – Measure consumed Infrastructure Resources

a. Power Delivery – Consumed power at UPS or other power sources based on maximum phase current and nominal voltage
b. Power Distribution – Count the number poles and breakers used

c. Cooling Generation – Add all heat sources inside the data center or calculate cooling consumption based on data available from cooling systems except of Free Cooling/Direct Air Economization
d. Cooling Flow – Measure total cooling airflow in m^3/hour or CFM based on manufacturers' specifications for all fans and blowers that deliver cooling air into data center IT space. Or measured total cooling liquid flow in gallons/min or m^3/sec based on manufacturers' specifications for cooling liquid delivery pumps.
e. Rack U Count – Count U spaces occupied by IT equipment for all IT racks

Step 5 – Calculate usages for all selected resources

a. Baseline IT Load = Measured IT Load / DC Design IT Capacity
    i. If a data center is designed to support 1MW of IT load, and the actual measured IT load at the moment of measurement is 600 kW, IT Load (Baseline) = 600 kW / 1,000 kW = 60%
b. Infrastructure Resource Usage for all selected elements = Consumed / Capacity
c. Instantaneous vs. average IUE™ measurements –
    i. One can take snap shot measurements of all infrastructure resource elements to arrive at an instantaneous IUE™ assessment
    ii. Alternatively, one can take average measurements of all infrastructure elements over a period of time (one month, one year, or whatever) to arrive at a time-averaged IUE™ assessment
    iii. Authors of this White Paper believe that use of both measurements is acceptable and will provide value to data center owners.

VI. Presenting IUE™ in Graphs

To help visualize and better understand how every infrastructure resource element included in IUE™ discussions behaves and relates to one another, bar charts and spider diagrams will be used. Graphs will also help reveal and illustrate usage efficiencies of all elements, thus pointing to areas where improvements can be made.

1. Figure 1 below depicts a perfect-world infrastructure resource usage scenario; resource element usage matches IT load usage and grows proportionally from 60%, to 80% and all the way to 100%.

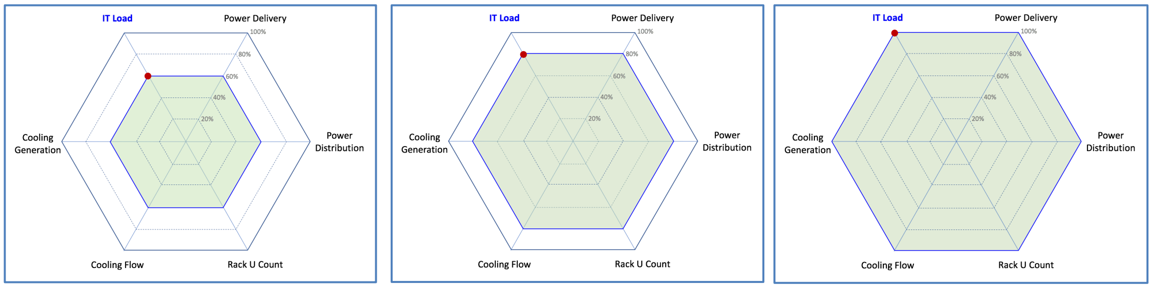

Figure 1. Perfect usage model – Resource usage matches IT load

2. Real world is far from perfect; data centers typically have usage of one or more resource elements outpacing IT load usage as a result of design flaws and/or operational inefficiencies. Figure 2 below illustrates an Air Cooling scenario where measured resource usage of Cooling Flow is maxed out (@ 100%) when IT load usage is only at 60% and usages of all other resource elements are between 62-70%
   a. The green shaded shape deviates from a perfect hexagon (as shown in Figure 1) and illustrates inefficiency.
   b. This data center has an overall 60% usage efficiency as only 60% of IT load can be utilized in relation to the design IT capacity.
   c. The IUE™ graphs clearly shows which resource element (i.e. Cooling Flow) is the biggest culprit for usage inefficiency and therefore serves as an alert to the operators and the owners to focus the primary improvement efforts on Cooling Flow.

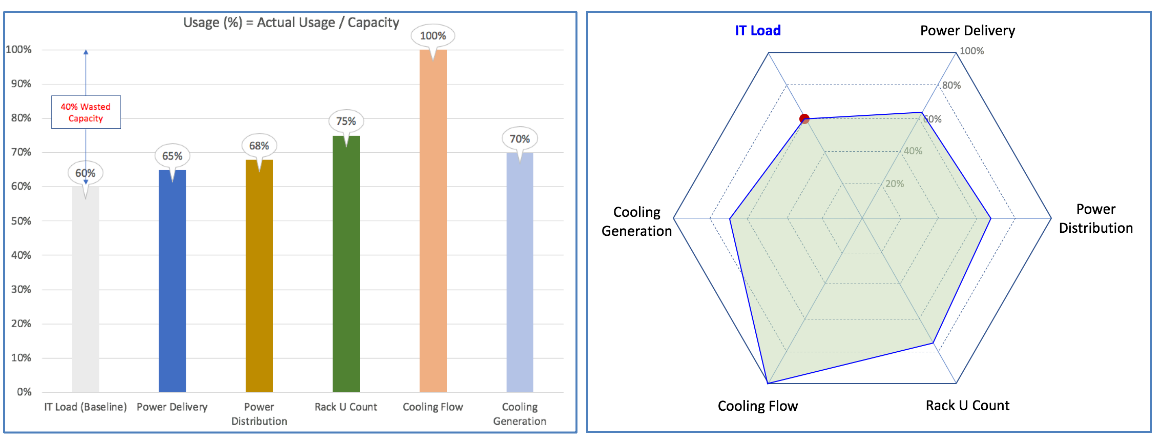

Figure 2. Reality – Resource element usages outpacing IT load usage with one element hitting 100%

3. Figure 3 below illustrates a scenario where infrastructure resource usages range between 60-80% with the baseline IT load usage of 60%

a. The green shaded shape is not a perfect hexagon, illustrating an inefficient resource usage scenario
b. While the graphs clearly show resource usage inefficiencies, the overall data center inefficiency is not readily discernable. One cannot, based on the available data, readily determine the overall usage efficiency as no resource usage has reached 100% yet to indicate stranded IT Load capacity and other stranded resources.

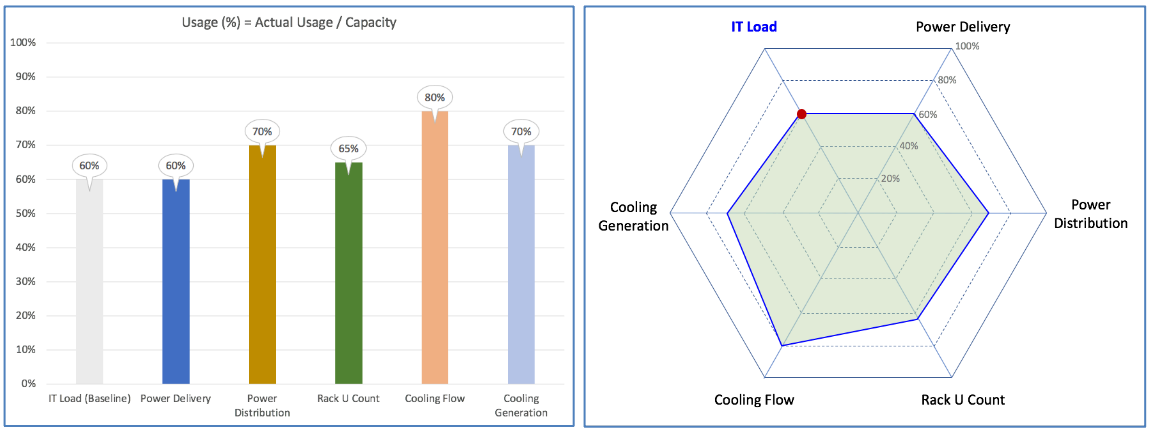

Figure 3. Reality – Resource element usages outpacing IT load

4. Figure 4 illustrates one practical way to estimate or project overall resource efficiency when no resource usage is directly measured at 100% as displayed in Figure 3
   a. All resource elements along with IT load are extrapolated **LINEARLY** until the most overused element, in this case Cooling Flow reaches 100%
   b. Baseline IT load is extrapolated linearly to 75% when Cooling Flow is fully used @ 100%
   c. All other resource elements are extrapolated similarly
   d. This data center is projected to have an overall usage efficiency of 75% (thus stranding 25% of design IT capacity)
   e. Dotted outline indicates IUE™ is an approximate analysis.

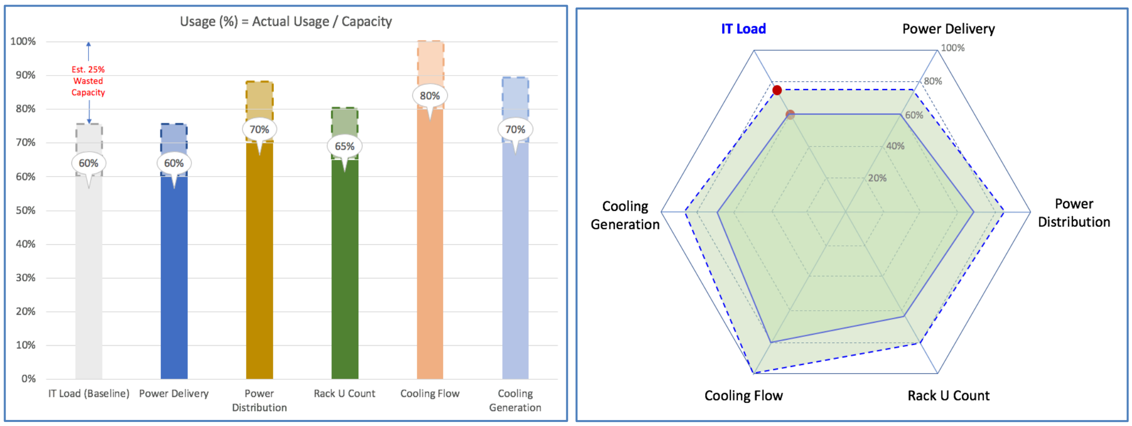

Figure 4. Linear extrapolation to reveal stranded resource

5. Notes on the linear extrapolation approach –
   a. The fashion of resource element increase in relation to IT load increase is not always deterministic. Linear extrapolation is an assumption, not a certainty. In fact, non-linear extrapolation is much closer to reality, but the challenge is the acquisition of the non-linear relationships
      i. Assuming a data hall originally houses 1,000 Type-A servers each consuming 500 watts of power and requiring 70CFM of cooling air. The data hall has an IT Load of 500KW and Cooling Flow of 70,000 CFM
      ii. Scenario 1 – Adding 500 more Type-A servers at the same workload leading to an IT Load of 750kW and Cooling Flow of 105,000CFM. In this case, IT Load and Cooling Flow will all increase linearly by a factor of 1.5X.
         . Conclusion – Linear extrapolation is valid
      iii. Scenario 2 – Increasing server workload – from 500 watts per server to 750 watts per server without changing the number and type of servers. In this case, IT load will increase by 1.5X whereas Cooling Flow will likely to increase, but at a rate different from 1.5X. Thus, the increase in Cooling Flow will not be linear with reference to IT load increase
         . Conclusion – Linear extrapolation is invalid
      iv. Scenario 3 – Adding an additional 1,000 Type-B servers, each consuming 250 watts and requiring 50 CFM per server. The resulting IT load will be 750kW and Cooling Flow of 120,000CFM. In this case, one will have a 1.5X increase in IT Load and 1.7X increase in Cooling Flow
         . Conclusion – Linear extrapolation is invalid

b. With proper design, testing, and documentation, it is possible to acquire the knowledge of the relationships between IT load increase and all other resource increases. The resource extrapolation required to reach IUE™ conclusions will therefore be based on actual data, instead of an assumption of linearity

c. For most data centers, there simply isn't an alternative way to deal with the non-linear nature of all infrastructure resource elements due to lack of relevant data. The next best thing is approximation – with the baseline of actual measurements of usages, treating all infrastructure resource elements as if they all behaved linearly in relation to IT load to achieve an approximate assessment on stranded resources. While this approach will not yield accurate IUE™ assessment, the linear approximation provides great value that can guide data center managers to focus their effort on reclaiming the most important resources

d. The analysis on usage efficiency illustrated in Figure 2 when one resource element is measured to have reached 100% usage is accurate based on measurement conditions, and therefore is a quantitative analysis. The analysis on usage efficiency illustrated in Figure 4, on the other hand, is an approximation based on data extrapolation and therefore is a qualitative analysis.

VII. Presenting IUE™ in Numbers

IUE™ graphs such as those in Figures 1-4 reveal a great deal of details about resource usage effectiveness; they clearly show the culprits of resource usage inefficiencies, quantitatively or qualitatively. As such, IUE™ graphs can help data center owners assess resource inefficiencies and identify opportunities to improve resource usage effectiveness and thus to reduce TCO and/or improve availability.

IUE™ can also be presented in simple numbers similar to PUE™. When presented in numbers, IUE™ becomes easy to read and understand without revealing details which may be proprietary or un-necessary in certain situations. Executives are potentially more interested in IUE™ presented in numbers while engineers in IUE™ presented in graphs.

In this White Paper, we propose that IUE™ presented in numbers be based on the baseline IT load:

1. IUE™ = 100% in Figure 1 and in the far left panel of Figure 5 – IT load can reach 100% of design capacity with all other resource elements remain at or below 100% usage

   a. Stranded power resource = 0%.
2. IUE™ = 60% as illustrated in Figure 2 and in the middle panel of Figure 5 – IT load can only reach 60% of design capacity
   a. Stranded power resource = (100 - 60)% = 40%.
3. IUE™ = 75% as illustrated in Figure 4 and in the far right panel of Figure 5 – IT load can only reach 75% of design capacity
   a. Stranded power resource = (100 - 75)% = 25%

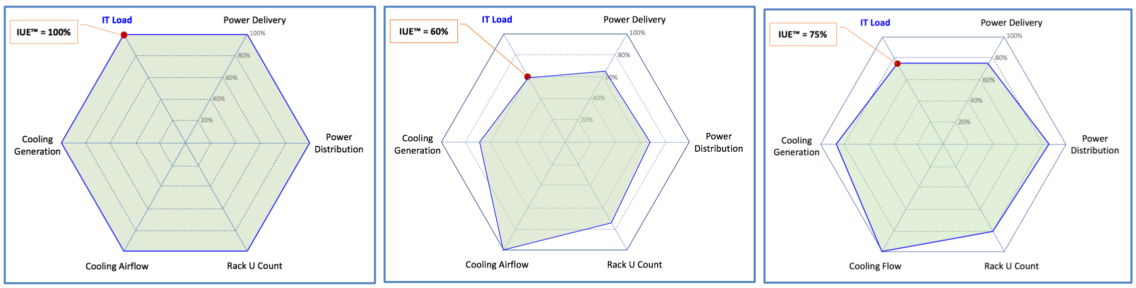

Figure 5. IUE™ presented in numbers vs. spider charts

VIII. Conclusion

Data center infrastructure resources are one of the most important considerations for data center owners. Not only can it affect IT infrastructure expandability, it also can have a major impact on CapEx and OpEx, given how extremely expensive it is to build data centers. TGGC believes that the IUE™ metric will have a positive impact on the industry in terms of improving data center resource efficiency and IT service availability. TGGC encourages industry stakeholders to rally around this new metric and participate in the adoption of IUE™ and further developing resource efficiency related metrics.

As volume of data and information continues to explode, data center resource efficiency will become even more critical. Resource efficiency can impact whether and when new expansive new facilities will need to be built. As competition among cloud providers becomes intense, those who can more efficiently utilize one of their most expensive assets, i.e. data center facilities, will have an edge over their peers. TGGC will continue to listen to industry stakeholders, including data center owners and operators, IT equipment vendors, infrastructure equipment vendors, policy makers, etc. and identify areas where data center resource efficiency improvements can be made. And TGGC will develop new metrics, white papers, technical guidelines, etc. to meet the needs of the industry to be more efficient in using precious resources, to gain competitive edge, and to meet social responsibilities.

IX. Acknowledgement

This white paper was initially developed under the auspices of The Green Grid Association (TGG) and supported by many then TGG members. Due to reorganization and other changes, this white paper was completed under and published by TGGC after a long delay. One TGG member who made significant contribution chooses not to appear as an author, and the names of several others were lost in the process of transition, for which the authors are truly sorry. The authors would like to extend their sincere gratitude to all those TGG members who made meaningful and significant contributions in the early stages of the development. It is fair to say that this white paper is the result of deep collaboration between The Green Grid Association and TGGC.

X. About TGGC

TGGC is an abbreviation of The Green Gauge Standards Committee, CCSA, a Chinese nonprofit, open industry consortium of end users, policy makers, and technology providers that works to promote ideas, standards, and best practices for green data centers to achieve sustainability and social responsibility. TGGC works closely with international colleagues and relevant organizations to draw on the best minds in the industry and builds a bridge between the Chinese data center industry and data center industry globally to enable great ideas to flow freely without boundaries and to benefit all. Additional information is available at www.tggchina.cn.