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ERE: A METRIC FOR MEASURING THE BENEFIT OF REUSE ENERGY FROM A DATA CENTER

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EXECUTIVE SUMMARY

The energy efficiency of data centers continues to be a critical factor in improving the overall energy use of IT equipment. In more and more new facilities, the energy from the data center is being reused in other parts of the facility or campus with beneficial results. These designs lack a metric with which can be tracked and compared. Power Usage Effectiveness (PUE) is a base data center infrastructure metric, but it does not consider these alternate uses for the waste energy. To account for these, The Green Grid has proposed and defined a new metric: Energy Reuse Effectiveness, or ERE.

ACKNOWLEDGEMENTS

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INTRODUCTION

This white paper introduces a new metric, Energy Reuse Effectiveness (ERE), which will provide the data center practitioner with greater visibility into energy efficiency in data centers that make beneficial use of any recovered energy from the data center. The paper presents specific rules on ERE's use, along with its theoretical and mathematical development. The paper concludes with several examples of site concepts that could employ the ERE metric.

PUE AS A METRIC OF DATA CENTER INFRASTRUCTURE EFFICIENCY

Since The Green Grid first published its white paper on Power Usage Effectiveness (PUE) and Data Center Infrastructure Efficiency (DCiE), TGG White Paper #1,[1] the term PUE has become the industry-wide, predominant metric for discussing data center efficiency.

ENERGY vs POWER

The original use of the term PUE was based upon the power drawn by the IT equipment, the power drawn by the cooling equipment, and the power losses in the electrical distribution system, hence the name Power Usage Effectiveness. Power is generally assigned units in kilowatts, and it represents an instantaneous measurement or "snapshot in time" of the power use. Electrical Energy (kWh) is the product of power (KW) times duration that it is applied (hours), so the units of energy would typically be kilowatt-hours. If a server with a power draw of 20 kilowatts drew exactly that much power for an hour, it would have used 20 kW-hrs of energy. Power is an instantaneous measurement, while energy is an integral over time. Typically we are more interested in energy but both have an important function in the design and operation of any data center.

The simplicity of the PUE metric actually allows the mathematics to be valid and consistent for either power OR energy. However, The Green Grid's PUE white paper WP #22 [2] removed any ambiguity over the question, as PUE is clearly defined as an energy metric.

REVIEW OF TGG PUE ACTIVITIES

WP #22 referred to above is the latest in the TGG series of PUE white papers. The Green Grid has published a number of papers on PUE but, as of this writing, the volume of PUE references is becoming excessive and The Green Grid is working on a consolidation plan for PUE references. The reader is encouraged to monitor The Green Grid website to stay abreast of the latest PUE documentation. This paper should be read in conjunction with the applicable and current PUE references to obtain a full understanding of the metric's concepts and acceptable use.

Another extensive reference is the joint ASHRAE and The Green Grid published book on real-time energy efficiency measurements.[3]

GAP IN METRIC FOR ENERGY REUSE

The extensive use of PUE and heightened focus on the metric has caused it to be used in situations outside of its currently defined methodology. One such specific area is data center waste energy reuse in a facility, with a resultant claimed PUE of less than 1.0. While the intent to be able to account for this reuse has generally been based upon laudable motives, the math and application has been in conflict with the specific definition and calculation method of PUE. No reuse energy term is allowed in the calculation and, by definition, the lowest possible PUE is 1.0.

NREL and LBNL

While PUEs of less than 1.0 were being improperly calculated and reported in the industry press and discussion forums, the National Renewable Energy Laboratory (NREL) and the Lawrence Berkeley National Laboratory (LBNL) were both developing new data centers with the ability to capture used energy for beneficial use elsewhere in the facility. Representatives of both labs suggested the development of a new metric to address the capture and measurement of the benefit. The Green Grid eagerly chose to work with the labs on this development.

THEORETICAL DEVELOPMENT

CONTROL VOLUME

With ERE, the concept of a control volume (CV) must be brought to the front of our discussion. In simplest terms, CV is the imaginary boundary around the data center and its infrastructure support areas, such that when energy crosses this boundary, it needs to be accounted for. In terms of PUE, the control volume is "drawn" around the data center at the point of handoff from the utility provider. In figure 1 below, PUE is simply the total energy at (A) plus (B) divided by the IT energy at (D). The control volume is the dashed line. For PUE and ERE, this is a critical distinction when alternate energy types and mixed-use buildings are analyzed. It is equally important to ensure all energy types are included in PUE and ERE. All primary energy types (such as fuel oil, natural gas, etc.) and secondary energy types (such as electricity, chilled water, etc.) that feed the data center should be included in the calculation.

Assuming there is no energy storage and the data center is at steady state, conservation of energy requires that the energy into the control volume must equal the energy out. In Fig. 1's simple schematic, that means A+B = F. This is oversimplified, as there are losses and heat generated at the cooling (A minus E), UPS, and PDU (B minus D) points as well, but this waste heat also must leave the CV. Once a CV is defined for a data center, it can be used to properly understand the ERE concept.
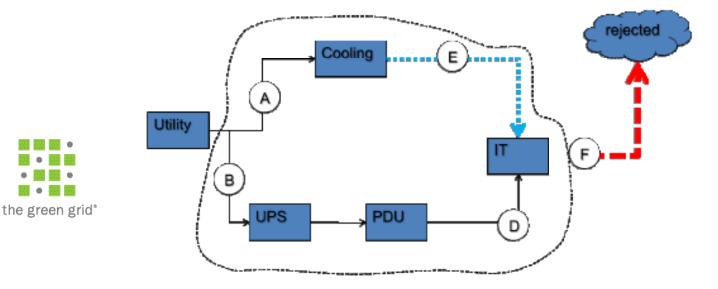
Figure 1. Simplistic data center components and control volume

* It is critical to include all energy types (primary and secondary) at the point of utility handoff. It is also critical to include all of the data center's energy consumption in the calculations, which includes but is not limited to generators, inside and outside lighting, fire detection & suppression, associated office/cubicle space for data center personnel, receiving areas, storage areas, and the same. For clarity the diagrams only show the large components to demonstrate the PUE and ERE concepts.

Only when there is energy being reused **outside** the data center CV will it be considered for ERE as reuse energy. Any energy reuse inside the control volume is already being accounted for in a lower PUE. Using it to also calculate a lower ERE is essentially double counting and not needed, as its benefit is already realized in a lower PUE. Examples of this are shown later in this paper.

In Figure 1, any portion of (F) that is reused outside the data center CV such as by a mixed-use building or a different building instead of rejected to the atmosphere, is considered reuse energy in determining ERE. However, the benefits of that reuse energy and the efficiency of that energy are outside the scope of ERE. While these concepts are important to a data center's overall energy use, they are too complex to try to define or measure in the context of what ERE is attempting to do, which is primarily based on the energy use and efficiencies of the data center itself. Future industry metrics should cover the benefit of the reuse energy.

To properly determine ERE, the practitioner will need to be able to identify and account for all energy streams crossing the CV **coming in** and any energy stream that will be used for beneficial data center use **going out** of the CV. The energy coming in would typically be electricity but could also be natural gas, diesel fuel, chilled water, or conditioned air from another space. These energies are also the same energies that need to be considered in calculating PUE. The energy leaving the CV will most often take the form of warm water or warm airflow; these are what ERE considers resued energy. However, any form of energy that is reused outside of the control volume needs to be accounted for. The authors are aware of an instance where excess

cooling from the data center is reused in another part of the site for cooling there. Whatever the form of the energy; the math and method hold. By definition, those unit processes that take advantage of the waste energy for other use are outside the CV. The simplest example would be some form of chiller being driven by data center waste heat. The energy to be considered for ERE is the waste heat going *into* the chiller and *not* the cooling energy delivered by the chiller to another part of the campus. Again, that unit process is outside of the data center CV as it is not a part of the required data center infrastructure.

A simple test of a specific technology employed in a data center to determine if the energy reuse should be considered in ERE is if the PUE of the data center would be different with or without that technology. If the technology causes a lower PUE, then it should not be considered as part of ERE. For example, if warm air from the data center is used to heat the UPS battery room in the winter, this will result in a lower PUE; therfore that heat reuse is *not* to be included when calculating an ERE. The heat from the data center, when trans-ferred to the battery room, stayed *within* the data center control volume and is therefore accounted for in lowering the PUE. It has no effect on ERE. If it had been used to heat an adjacent, non-data center space (e.g., a cafeteria next-door), then the heat crossed the CV and counts in ERE but not PUE. (For more examples of ERE usage, see pg. 11.)

ENERGY MEASUREMENT AT THE CONTROL BOUNDARY

There are a number of energy types and methods of measuring them (See Table 1). A range of conversion fac-tors and measurement techniques can be found at the U.S Energy Information Administration (EIA) Website [4] and the ASHRAE/TGG book on energy measurement. [3]

Energy Type	Typical Units	Comments
Electricity	kW-hrs	An annualized energy consumption is the basis.
Diesel Fuel	Gallons	How many gallons of fuel per year? There are roughly 2.5 kW-hrs in a gallon of diesel fuel.
Natural Gas	Cu-meter (cu-ft)	How many cu-ft of gas per year? There are roughly 10.6 kW-hrs in a cu-meter (or 0.3 kW-hrs in a cu-ft) of natural gas.
Hot/Cold Water	Cu-meter (gallons)	How much warm/cold water was used per year? There are roughly 1.16 kW-hrs in a cu-meter of water (or $4.4X10^{-3}$ kW-hrs in a gallon) that changes 1˚C*
AIrflow	Cu-meter (cu-ft)	How much warm/cold air was used per year? There are roughly $2.5x10^{-4}$ kW-hours in a cu-meter of air (or $7.1 x 10^{-6}$ kW-hrs in a cu-ft) that changes 1˚C**

Table 1. Energy measurement methods at the control volume boundary

Please note: The above values are calculated from published thermal physical properties of the individual fluids. The above table is provided as a guide for informational purposes only. A detailed engineering analysis should be completed to get the specific values for each individuals application.

* As a first estimate, use a difference in temperature between the water supply and return temperatures. For example, if the water is leaving at 40˚C and returning at 25˚C, there is a 15˚C temperature difference, which would mean 6.6x10-2 kW-hrs for every gallon of water used.

** As a first estimate, use a difference in temperature between the warm air and the air it is replacing. For example, if 30˚C air is being fed to a 20˚C room, then use 10˚C as the temperature difference, which would mean 1.9x10-4 kW-hrs for every cu-ft of air used.

MATHEMATICAL DEVELOPMENT

NUMERATOR SUBTRACTION METHOD

Recall the definition of PUE: Total Energy divided by IT Energy:

$$PUE = \frac{Total\ Energy}{IT\ Energy}$$

This can be expanded and notated as:

$$PUE = \frac{Cooling+Power+Lighting+IT}{IT}$$

Where *Cooling* represents energy used by the entire cooling system attributable to the data center, *Power* is the energy lost in the power distribution system through line-loss and other infrastructure (e.g., UPS or PDU) inefficiencies, and *Lighting* represents the energy used to light the data center and support spaces. A miscellaneous (*Misc*) term could be added here to be more complete, but this paper leaves it out for the sake of brevity. *IT* is the energy used by all of the IT equipment (servers, network, storage) in the data center.

The values are all units of energy. So if energy from the data center is used in another location and reduces the energy the site would need to buy, procure, or generate, it can be accounted for in the new metric:

$$ERE = \frac{Cooling+Power+Lighting+IT-Reuse}{IT}$$

ENERGY REUSE FACTOR (ERF) METHOD

An alternate derivation is also proposed, the goal being a relationship that links ERE and PUE , in the form of:

$$ERE = c×PUE$$

Where "c" is some factor to be determined here.

DEFINED ERF

An Energy Reuse Factor (ERF) can be defined as:

$$ERF = \frac{Reuse\ Energy}{Total\ Energy}$$

ERF is the ratio of the data center energy that is reused elsewhere in the facility and the total energy brought into the data center control volume (including IT, cooling, power, lighting, etc.) Total energy is essentially the numerator of PUE.

Note that ERF will range from 0 to 1.0. The value at 0.0 means NO energy is reused, while a value of 1.0 means all of the energy brought into the data center control volume is reused.

ERE can then be defined as:

$$ERE = (1\text{-}ERF) \times PUE$$

Note that as ERF goes to 0 (no energy reuse), ERE will equal PUE, as one would expect for a well-behaved metric.

METHOD EQUIVALENCE

Both methods shown above will yield the same value of ERE, therefore:

$$ERE = (1\text{-}ERF) \times PUE = \frac{Cooling + Power + Lighting + IT\text{-}Reuse}{IT}$$

The algebraic proof of this is left as an exercise for the reader, but Table 2 provides a simple numerical example.

Parameter	Value
IT Load	20,000 kW-hrs
Cooling Energy Used	10,000 kW-hrs
Power Delivery Loss	4,500 kW-hrs
Lighting	500 kW-hrs
Total (sum of above)	35,000 kW-hrs
Reuse Energy	6,000 kW-hrs

Table 2. Example data center data for ERE calculation

For the sample data center in Table 2:

$$PUE = \frac{Cooling + Power + Lighting + IT}{IT}$$

$$PUE = \frac{10000 + 4500 + 500 + 20000}{20000} = 1.75$$

Using the Numerator Subtraction method

$$ERE = \frac{Cooling+Power+Lighting+IT\text{-}Reuse}{IT}$$

$$ERE = \frac{10000+4500+500+20000\text{-}6000}{20000} = 1.45$$

Using the ERF method:

$$ERF = \frac{Reuse\ Energy}{Total\ Energy}$$

$$ERF = \frac{6000}{35000} = 0.17$$

$$ERE = (1\text{-}ERF) \times PUE$$

$$ERE = (1\text{-}0.17) \times 1.75 = 1.45$$

Both methods, *Numerator Subtraction* and *ERF,* return the same value, ERE = 1.45.

Further examination of the properties of PUE and ERE brings out another important result. The range of values for PUE is mathematically bounded from 1.0 to infinity. A PUE of 1.0 means 100% of the power brought to the data center goes to IT equipment and none to cooling, lighting, or other non-IT loads... the proverbial server in a dark tent. For ERE, the range is 0 to infinity. ERE does allow values less than 1.0. An ERE of 0 means that 100% of the energy brought into the data center is reused elsewhere, outside of the data center control volume.

Note that an ERE of 1.0 does NOT imply an efficient base data center infrastructure. It could represent a very efficient design (PUE = 1.2) with a small amount of energy reuse (ERF = 0.17 and ERE = (1-0.17)*1.2 = 1.0) or an inefficient base design (PUE = 2.0) with a lot or energy reuse (ERF = 0.50 and ERE = (1-0.5)*2.0 = 1.0). This is why both PUE and ERE are useful metrics in the analysis of data centers that reuse energy. The theoretical limits of PUE, ERE, and ERF can be summarized as:

$$1.0 \leq PUE \leq \infty$$

$$0 \leq ERE \leq \infty$$

$$0 \leq ERF \leq 1.0$$

EXAMPLES OF ERE USAGE

The concept and application of PUE has been beneficial to the industry but also challenging on occasion, due to misuse. ERE is a more precisely defined metric than PUE was in its first white paper. To assist in ERE's quick adoption through widespread understanding, the following examples are provided. The recurrent theme in all of these examples is if the beneficial energy reuse occurs outside the data center and its support infrastructure (more technically defined as the data center's control volume), then ERE is the correct metric to use. Otherwise, if reuse occurs within the control volume, PUE is the correct metric.
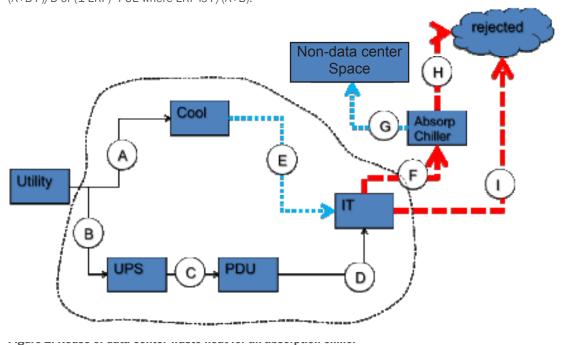
CORRECT USE OF ERE

WARM AIR/WATER REUSE ELSEWHERE ON CAMPUS

An example of straightforward energy reuse is heat from the data center being used to heat adjacent, non-data center spaces. The energy in the heating water or heating air that leaves the data center would be the reuse energy, and its measurement would involve calculation of ERE.

HEAT TO RUN AN ABSORPTION CHILLER

Figure 2 shows a schematic for a high-level reuse scenario. The control volume is delineated by the dashed line. In this example, waste heat is used to drive the absorption chiller (F). The cooling energy from that chiller is used to cool an ancillary non-data center space (G). For the calculation of ERE, the definition requires the measurement of the energy crossing the control volume to be considered as the reuse energy. Again, the value of energy crossing the control volume is the energy at (F). In this case, the PUE is (A+B)/D. The ERE is (A+B-F)/D or (1-ERF)*PUE where ERF is F/(A+B).

Figure 2. Reuse of data center waste heat for an absorption chiller.

HEAT TO GENERATE ELECTRICITY USED ELSEWHERE

There are technologies in development for reverse heat engines that can create electricity from heat. Schematically, this would be equivalent to that equipment being in the same location as the absorption chiller. In either case, the reuse energy is measured where it crosses the control volume boundary. Only the value of (F) should be considered in calculating ERE.

INCORRECT USE OF ERE

HEAT TO RUN AN ABSORPTION CHILLER OR GENERATE ELECTRICITY FOR USE IN THE DATA CENTER

In the case of energy reused to drive an in-data center unit process, the reuse will increase efficiency of the space, but this benefit will be captured in PUE. In this case, that capital investment is made to directly improve efficiency of the data center and as such, PUE will be reduced. Figure 3 depicts this arrangement, with the CV encompassing the absorption chiller. In this case, (I) and (H) both leave the CV but neither are reused.

In the case of Figure 3, there is no ERE. PUE is equal to (A+B)/D. Note that one would fully expect the PUE of the data center in Figure 3 to be lower than the PUE in Figure 1. The benefit of the absorption chiller is taken into account in Figure 3's PUE. The PUE should be less because the added beneficial cooling from (G) would reduce the amount of cooling energy needed at (E) and, therefore, at (A).
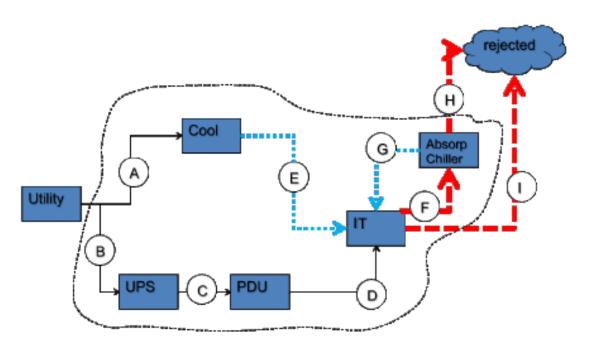

Figure 3. Schematic showing reuse of heat within the data center

HEATING A DATA CENTER SUPPORT SPACE OR PREHEATING OF DATA CENTER GENERATORS

As discussed earlier in the paper, simple reuse of data center heat to heat the data center's battery space or electrical room would not make that facility a candidate for ERE. That reuse, which simply reduces the amount of energy needed to be procured for the data center and its overall operation, will also reduce PUE but is not part of any ERE metric application. Similarly, the case where waste heat may be used to preheat generators for data center electricity production is not an ERE-type application. Rather, it is an investment to obtain a data center self-contained energy efficiency gain and it will simply reduce PUE.

SPLIT-SYSTEM COMPLICATIONS

HEAT TO RUN AN ABSORPTION CHILLER

Consider Figure 3 again. If the cooling energy (G) turns out to be used both in the data center and in a non-related space, the amount of energy (F) that is reused must be appropriated for each space. A first-order approximation could be as simple as a ratio of chilled water flow. If 75% of the cooling from the absorption chiller was used outside the data center, then 75% of the energy reused (0.75*F) should be included in calculating ERE. Such complex designs are beyond the scope of this paper, but the guidelines presented should be able to be applied to all scenarios.

FUTURE AND COMPLEMENTARY WORK

pPUE

The Green Grid is currently exploring the concept of the Partial PUE (pPUE) where a PUE-like value for a sub-system can be measured and reported. A simple example of an eligible subsystem is a container. An overall PUE of a container-based data center must necessarily include any energy used by the base facility supporting the containers as well as the container itself. However, in this context PUE can be too high-level a metric, allowing no visibility between the infrastructure penalty attributable to the base infrastructure versus the container itself or between two different containers themselves. pPUE will provide a more refined methodology for looking at the next level down.

ENERGY STAR FOR DATA CENTERS

The EPA has recently released the ENERGY STAR for data centers program, which involves comparison of data centers and recognition of the top performers. The primary metric used in the program is PUE, based upon source energy. This allows any type of energy to be used and still result in an appropriate comparison. The EPA methodology can provide additional insight into appropriate methods for measuring or calculating energy in, for example, a chilled water or natural gas flow scenario. (See reference 5 for further information.) Discussions of ERE and its impact on the ENERGY STAR program are expected.

METRICS

Today there are many metrics that communicate different aspects of data center efficiencies, and there are more being created. As with assessing the financial health of a business, one should not look at one metric in isolation. The same is true for assessing the efficiency of a data center. As stated earlier, both PUE and ERE are useful metrics in the analysis of data centers that reuse energy. If one only calculated ERE, one would not be able to identify whether the data center infrastructure represented a highly efficient design and a small amount of energy reuse or a great deal of energy reuse and an inefficient infrastructure design. Calculating both provides data center owners/operators more visibility into where efficiencies (or opportunities for further efficiency) exist.

SUMMARY

The need for an ERE metric is based upon the continued focus of energy efficiency in the data center. When additional steps to reuse data center energy elsewhere on the campus or in a different building are made, it is important to have a metric that can accurately reflect the performance of the investment and allow tracking and comparison with the same degree of success that PUE has provided. ERE has been developed and presented here to accomplish that.

Remember the simple test; if a technology helps reduce PUE it is likely to be self-contained in the data center environs (Control Volume) and should not be part of any ERE analysis. If the energy reuse is outside of the data center, PUE should not change or be affected.

REFERENCES

1   GREEN GRID METRICS: Describing data center Power Efficiency, Green Grid WP #1, 2007

2   USAGE AND PUBLIC REPORTING GUIDELINES FOR THE GREEN GRID'S INFRASTRUCTURE METRICS (PUE/DCIE), Green Grid WP #22, 2009

3   ASHRAE. 2009. Real-Time Energy Consumption Measurements in data centers. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

4   Energy Calculators,
    http://www.eia.doe.gov/kids/energy.cfm?page=about_energy_conversion_calculator-basics, 2010

5   ENERGY STAR data center Energy Efficiency Initiatives,
    http://www.energystar.gov/index.cfm?c=prod_development.server_efficiency#rating_dcdp, 2010