SC12 ENERGY EFFICIENCY METRICS
Why Metrics?
- We can’t manage what we don’t measure
- Trends over time
- Comparisons between clusters or data centers

What makes a good metric?
- a) simplicity, b) it matters, c) measureable, d) actionable

What we will cover
- Data Center Energy Efficiency
- Infrastructure Specific Metrics
- Sustainability
- Compute Performance
THE DATA CENTER

Site

Utility → UPS → PDU → IT Equipment

Data Center

Chiller Plant → CRAC Unit

Data Center

Utility

Site

IT Equipment

PDU

CRAC Unit

Chiller Plant

Data Center

Utility
PUE – SIMPLE AND EFFECTIVE

PUE is defined in terms of total annual energy and total annual IT energy, allowing a more valid site-to-site comparison.

\[
PUE = \frac{\text{Total Energy}}{\text{IT Energy}} = \frac{\text{Cooling} + \text{PowerDistribution} + \text{Misc} + \text{IT}}{\text{IT}} = \frac{a + b}{d}
\]
Green Grid, ASHRAE, DOE, EPA and others agreed to detailed PUE definition.
## PUES: REPORTED AND CALCULATED

<table>
<thead>
<tr>
<th>Site</th>
<th>PUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global bank’s best data center (of more than 100)</td>
<td>2.25</td>
</tr>
<tr>
<td>EPA Energy Star Average</td>
<td>1.91</td>
</tr>
<tr>
<td>Intel average</td>
<td>&gt;1.80</td>
</tr>
<tr>
<td>Intel Jones Farm, Hillsboro</td>
<td>1.41</td>
</tr>
<tr>
<td>ORNL</td>
<td>1.25</td>
</tr>
<tr>
<td>T-Systems &amp; Intel DC2020 Test Lab, Munich</td>
<td>1.24</td>
</tr>
<tr>
<td>Google</td>
<td>1.16</td>
</tr>
<tr>
<td>Leibniz Supercomputing Centre (LRZ)</td>
<td>1.15</td>
</tr>
<tr>
<td>Containers</td>
<td>1.1-1.6</td>
</tr>
<tr>
<td>National Center for Atmospheric Research (NCAR)</td>
<td>1.10</td>
</tr>
<tr>
<td>Yahoo, Lockport</td>
<td>1.08</td>
</tr>
<tr>
<td>Facebook, Prineville</td>
<td>1.07</td>
</tr>
<tr>
<td>National Renewable Energy Laboratory (NREL)</td>
<td>1.06</td>
</tr>
</tbody>
</table>
MORE ON PUE

- Partial PUE (pPUE)
- DCiE – 1/PUE.... No longer used
- Power or Energy?
  - Both!
- Site or Source?
  - Source based, Energy conversion factors needed
  - All Electric data centers: $PUE_{source} = PUE_{site}$
- Subscripts
  - Global Harmonization has added $PUE_0$, $PUE_1$, $PUE_2$, $PUE_3$
RATING SYSTEMS

- Energy Star for Data Centers
- European Union Code of Conduct for Data Centers
- The Green Grid
- LEED
- Uptime Institute Tier Rating System
  - Tier 1 thru Tier IV
ERE DEFINITION

\[ PUE = \frac{\text{Total Energy}}{\text{IT Energy}} \]

\[ PUE = \frac{\text{Cooling} + \text{Power} + \text{Lighting} + \text{IT}}{\text{IT}} \]

\[ ERE = \frac{\text{Total Energy} - \text{Reused Energy}}{\text{IT Energy}} \]

\[ ERE = \frac{\text{Cooling} + \text{Power} + \text{Lighting} + \text{IT} - \text{Reused}}{\text{IT}} \]
Define energy reuse factor (ERF) as:

\[
ERF = \frac{\text{Reuse Energy}}{\text{Total Energy}}
\]

Then:

\[
ERE = (1 - ERF) \times PUE
\]

And finally:

\[
ERE = \frac{\text{Cool + Pwr + Light + IT - Reused}}{\text{IT}} = (1 - ERF) \times PUE
\]

ERF and PUE are mathematically related, but differ and need to defined and reported clearly.
ERE – ADDS ENERGY REUSE TO THE PUE CONCEPT

\[ ERE = \frac{\text{Total Energy} - \text{Reuse Energy}}{\text{IT Energy}} \]

\[ = \frac{\text{Cooling} + \text{PowerDistribution} + \text{Misc} + \text{IT} - \text{Reuse}}{\text{IT}} = \frac{a + b - g}{d} \]
WATER AND CARBON - INCREASING FOCUS ON SUSTAINABILITY

- Two new metrics for Data Center sustainability
- Published by The Green Grid
- Development of the Metrics will give better focus on Data Center sustainability
CUE – CARBON USAGE EFFECTIVENESS

\[ PUE = \frac{\text{Total Facility Energy}}{\text{IT Energy}} \]

\[ CUE = \frac{\text{Total CO emissions caused by the Total Data Center Energy}}{\text{IT Energy}} \]

CUE ~ kgCO₂eq/kWh
Includes scope 1 and scope 2, but not scope 3
WUE – WATER USAGE EFFECTIVENESS

\[ PUE = \frac{\text{Total Facility Energy}}{\text{IT Energy}} \]

\[ WUE = \frac{\text{Annual Site Water Usage}}{\text{IT Energy}} \]

\[ WUE_{\text{source}} = \frac{\text{Annual Source Energy Water Usage} + \text{Annual Site Water Usage}}{\text{IT Energy}} \]

\[ WUE \sim \text{Liters/kWh} \]
$\text{ITUE} = \frac{\text{total energy into the IT equipment}}{\text{total energy into the compute components}} = \frac{i}{g}$
$$PUE = \frac{\text{Total Energy}}{\text{IT Energy}} = \frac{a + b}{d}$$

$$\text{ITUE} = \frac{\text{Total Energy}}{\text{Compute Energy}} = \frac{g}{i}$$

$$TUE = \text{ITUE} \times PUE = \frac{a + b}{i}$$
INFRASTRUCTURE METRICS

- **Power / area** – (W / sq. ft. or W / m²)
- **Power / rack** – (kW / rack)
- **Cost / area** – ($ / sq. ft., € /m²)
- **Cost / power** – ($ /kW, € /kW)
- **Area/Area** – Data Center “white space” / Infrastructure space
- **Cost/Cost** – Data Center / IT equipment
- **Percentage of cost** – % of each Civil/Structural/Architectural (CSA), Power, and Cooling
- **Cost/Cost** – Operational cost / purchase cost
- **Area/Rack** – sq ft / rack
We need a miles-per-gallon metric for compute efficiency

Recall: what makes a good metric?
- a) simplicity, b) it matters, c) measureable, d) actionable

We have had decent ways to measure “miles” but the “gallons” have been missing

Good recent progress. Let’s review....
Data from spec.org

**SPECPOWER**

**LOWER is BETTER**

**HIGHER is BETTER**

**BETTER EFFICIENCY**

**HIGHER PERFORMANCE**

**LOWER POWER**

**SSJ Ops**

**HIGHER is BETTER**
SPEC OMP2012

- SPEC OMP2012 updated from previous metrics (SPEC OMP2001)
- SPEC OMP2012 adds SPECpower power measuring tools and methods (Perf/Watt)
- Open MP – runs on shared memory systems
- BoF: Tuesday, 5:30-7:30, Room 155-B, SPEC HPG Benchmarks For Next Generation Systems
- http://www.spec.org/omp2012/
EEHPC WG working on the denominator
- How do we measure the energy used in the benchmark run?

Version 2 Beta-testing completed by a range of participating HPC Centers

The Green Grid is a collaborator

Working with Top 500, Green 500, and Green Graph 500

BoF: Wednesday, 12:15-1:15, Room 250-AB, Setting Trends for Energy Efficiency

\[ \varepsilon = \frac{\text{Perf}}{\text{Watt}} \]

http://eehpcwg.lbl.gov/