

# SC12 ENERGY EFFICIENCY METRICS

Michael K  
Patterson,  
PhD, PE

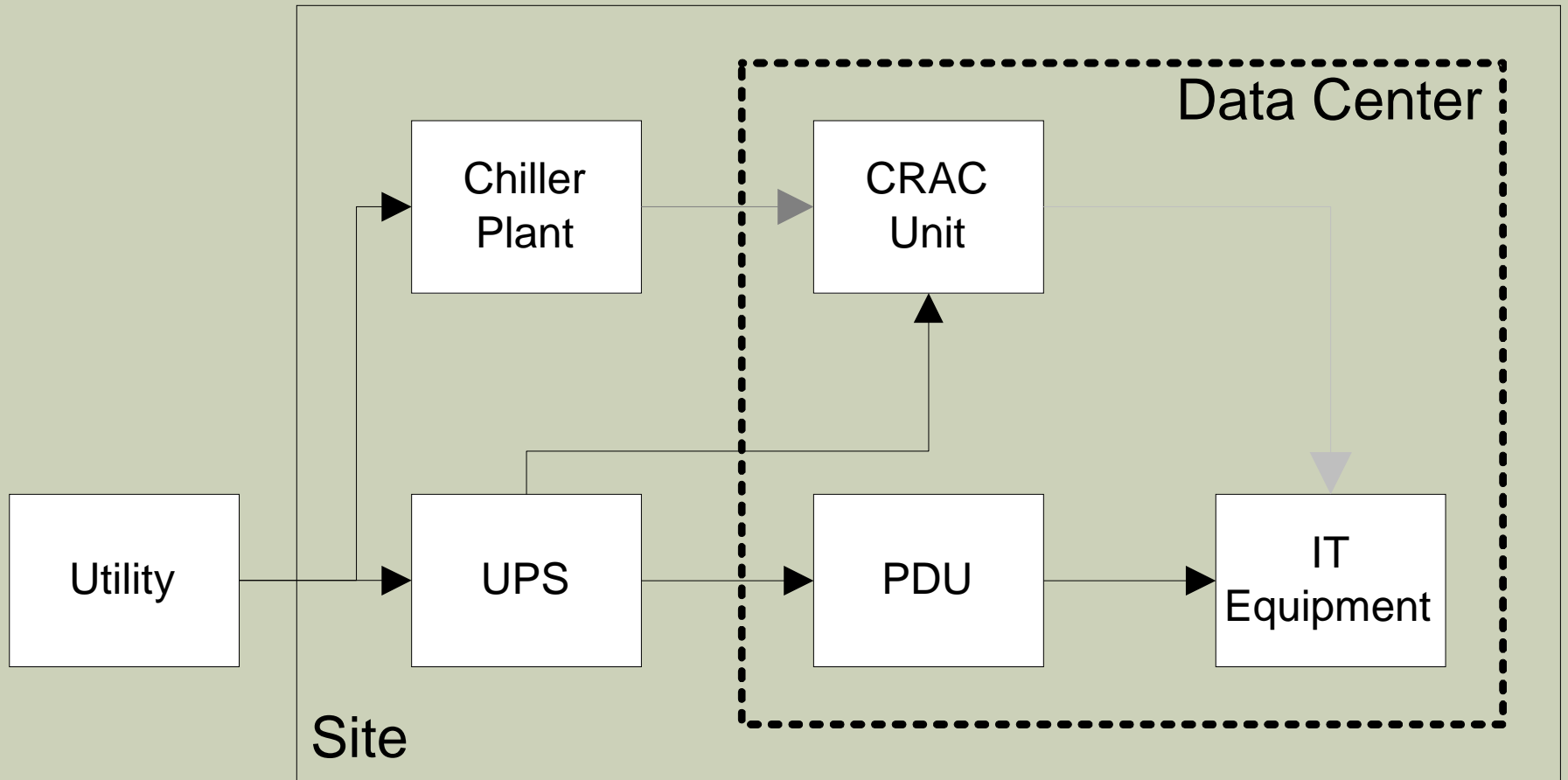
Exascale  
System  
Architecture  
Pathfinding

Intel  
Corporation

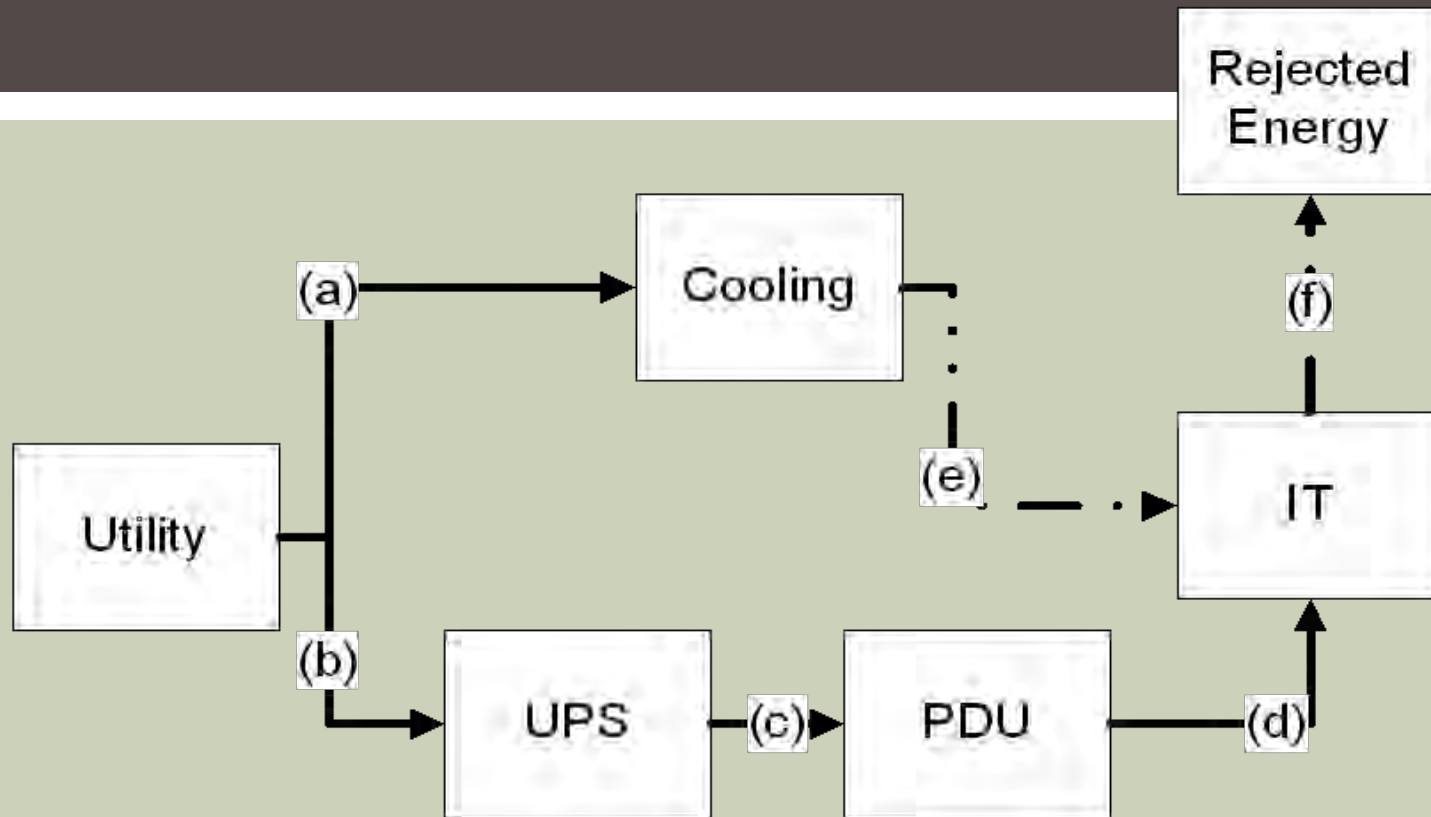
# OVERVIEW

- **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) measurable, d) actionable
- **What we will cover**
  - Data Center Energy Efficiency
  - Infrastructure Specific Metrics
  - Sustainability
  - Compute Performance

# THE DATA CENTER



# PUE – SIMPLE AND EFFECTIVE



$$PUE = \frac{\text{Total Energy}}{\text{IT Energy}} = \frac{\text{Cooling} + \text{Power Distribution} + \text{Misc} + \text{IT}}{\text{IT}} = \frac{a + b}{d}$$

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

**Recommendations for Measuring and Reporting  
Overall Data Center Efficiency**

Version 2 – Measuring PUE for Data Centers

17 May 2011



**Green Grid,  
ASHRAE, DOE,  
EPA and others  
agreed to  
detailed PUE  
definition**



# PUES: REPORTED AND CALCULATED

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

# MORE ON PUE

- Partial PUE (pPUE)
- DCiE –  $1/\text{PUE}$ .... No longer used
- Power or Energy?
  - Both!
- Site or Source?
  - Source based, Energy conversion factors needed
  - All Electric data centers:  $\text{PUE}_{\text{source}} = \text{PUE}_{\text{site}}$
- Subscripts
  - Global Harmonization has added  $\text{PUE}_0$ ,  $\text{PUE}_1$ ,  $\text{PUE}_2$ ,  $\text{PUE}_3$

# 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

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

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

---

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

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

# ERE ALTERNATE DEVELOPMENT

Define energy reuse factor (ERF) as:

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

Then:

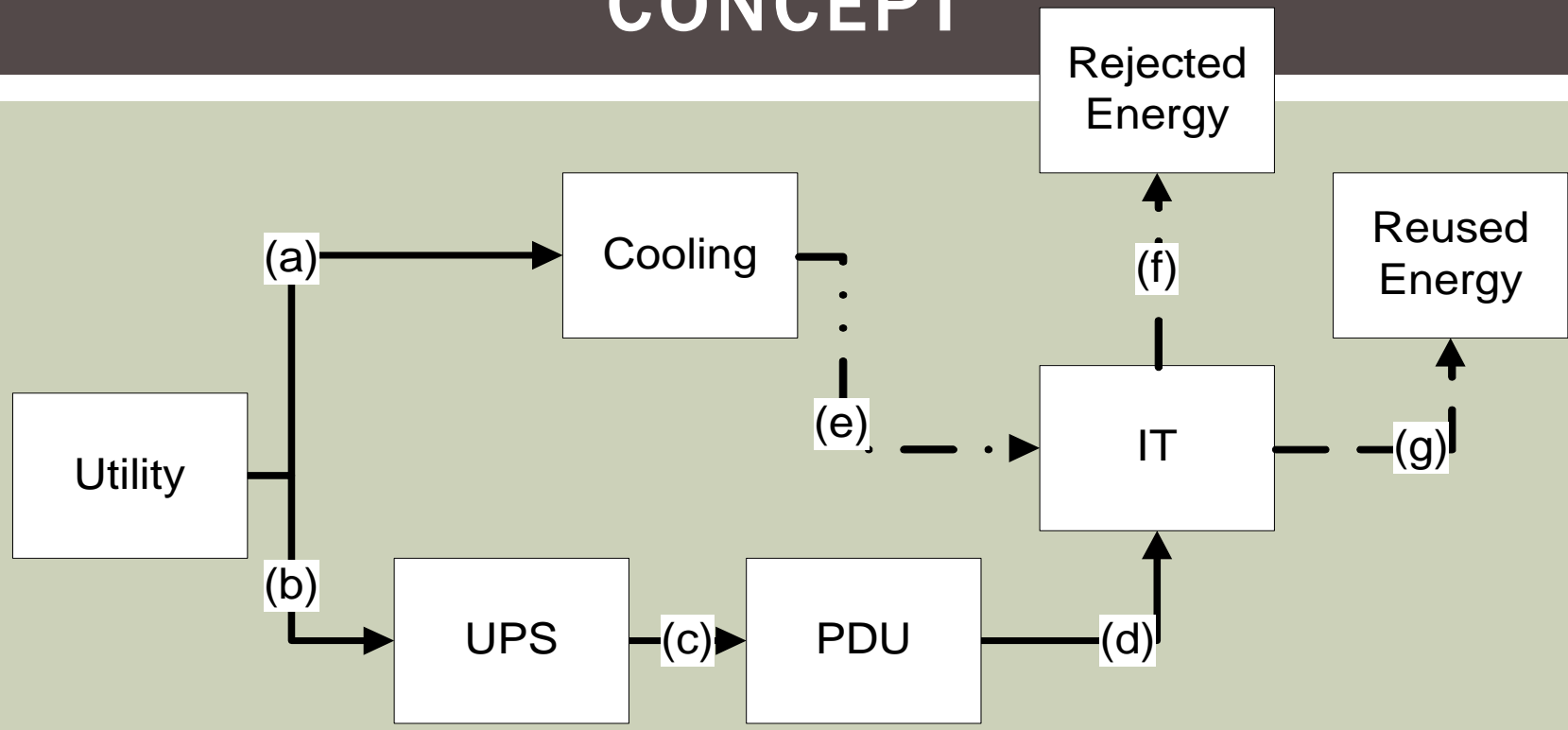
$$\text{ERE} = (1 - \text{ERF}) \times \text{PUE}$$

And finally:

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

ERF and PUE are mathematically related, but differ and need to be 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

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

$$CUE = \frac{\textit{Total CO emissions caused by the Total Data Center Energy}}{\textit{IT Energy}}$$

**CUE ~ kgCO<sub>2</sub>eq/kWh**

**Includes scope 1 and scope 2, but not scope 3**

# WUE – WATER USAGE EFFECTIVENESS

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

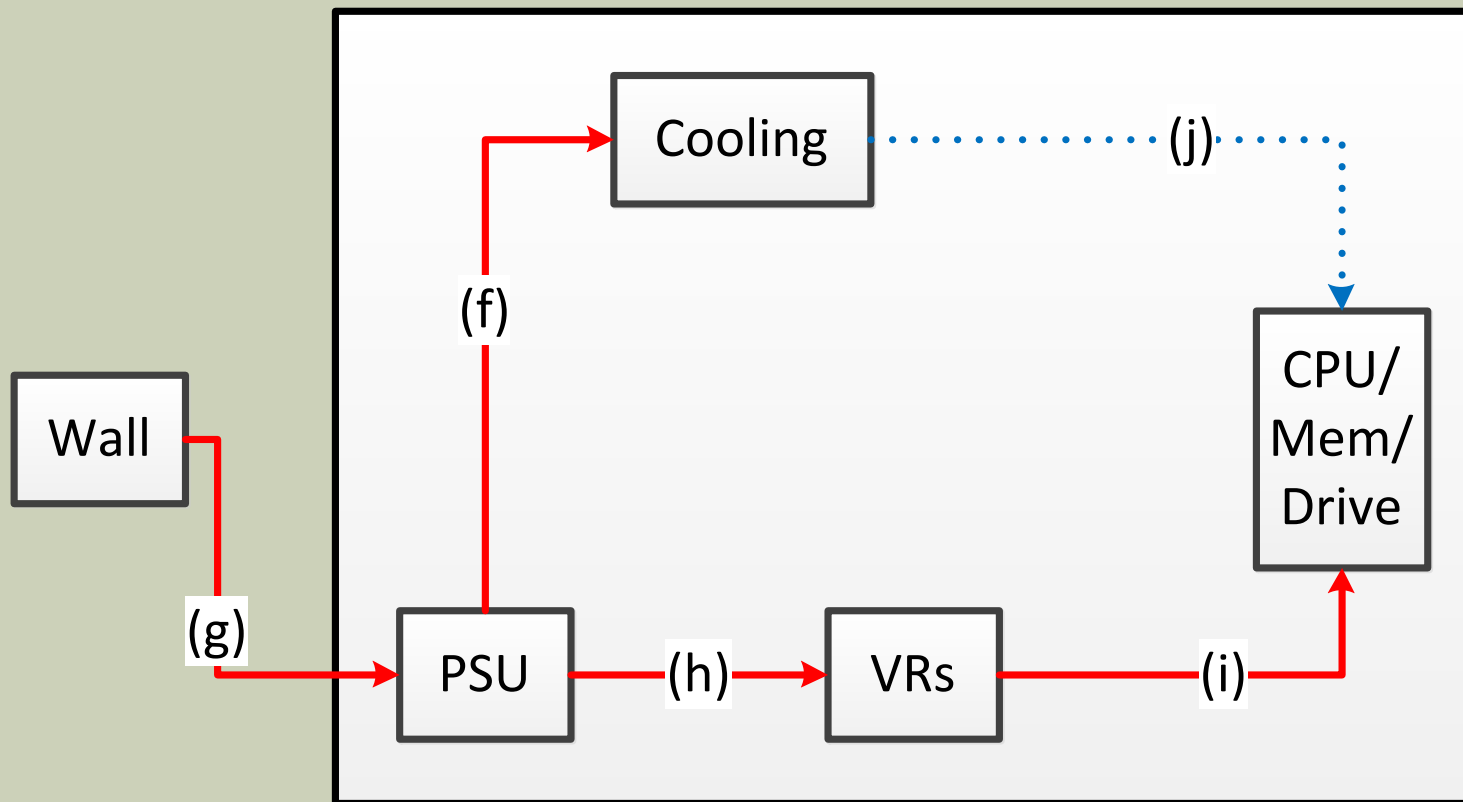
$$WUE = \frac{\textit{Annual Site Water Usage}}{\textit{IT Energy}}$$

$$WUE_{\textit{source}} = \frac{\textit{Annual Source Energy Water Usage} + \textit{Annual Site Water Usage}}{\textit{IT Energy}}$$

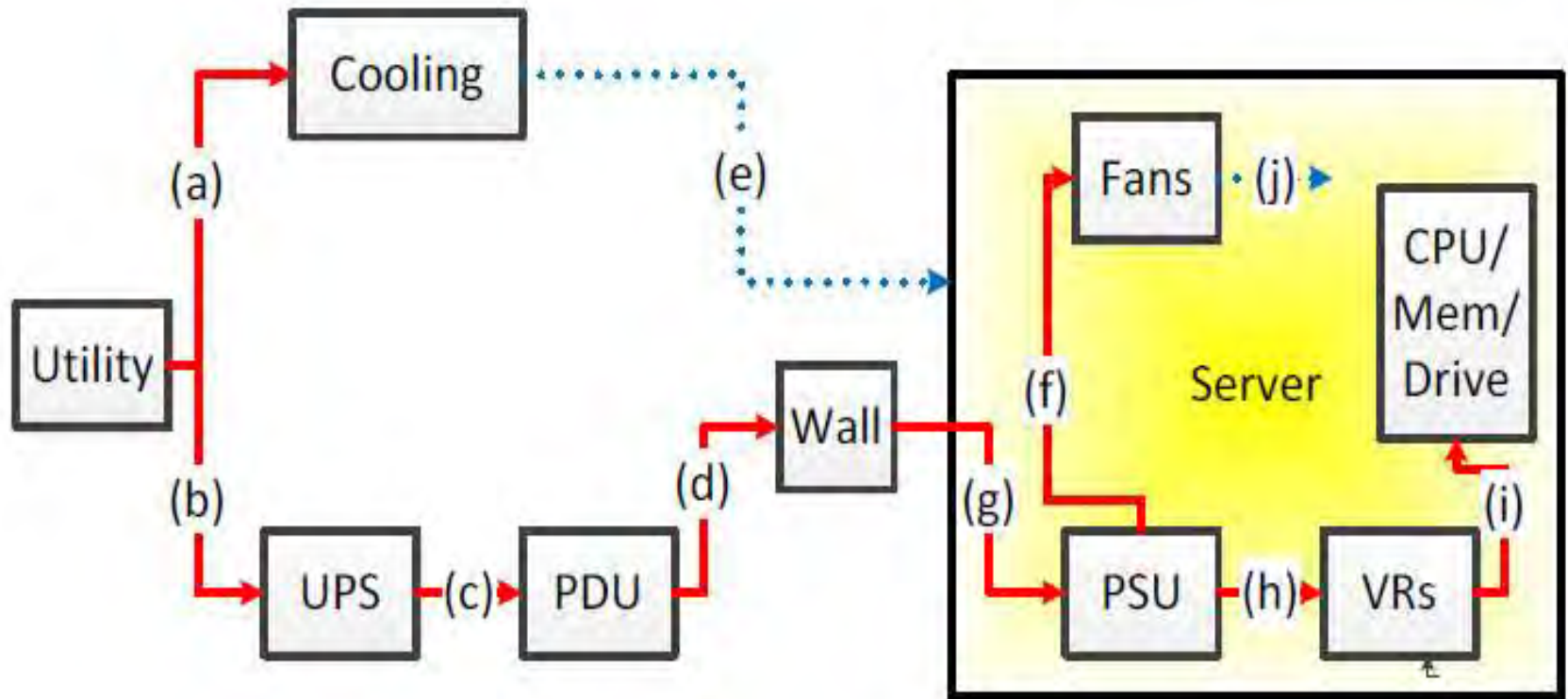
**WUE ~ Liters/kWh**

# ITUE

$$ITUE = \frac{\text{total energy into the IT equipment}}{\text{total energy into the compute components}} = \frac{i}{g}$$



# TUE



$$PUE = \frac{\text{Total Energy}}{\text{IT Energy}} = \frac{a + b}{d}$$

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

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



# INFRASTRUCTURE METRICS

- Power / area - (W / sq. ft. or W / m<sup>2</sup>)
- Power / rack - (kW / rack)
- Cost / area - (\$ / sq. ft., € /m<sup>2</sup>)
- 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

# COMPUTE EFFICIENCY

- 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....

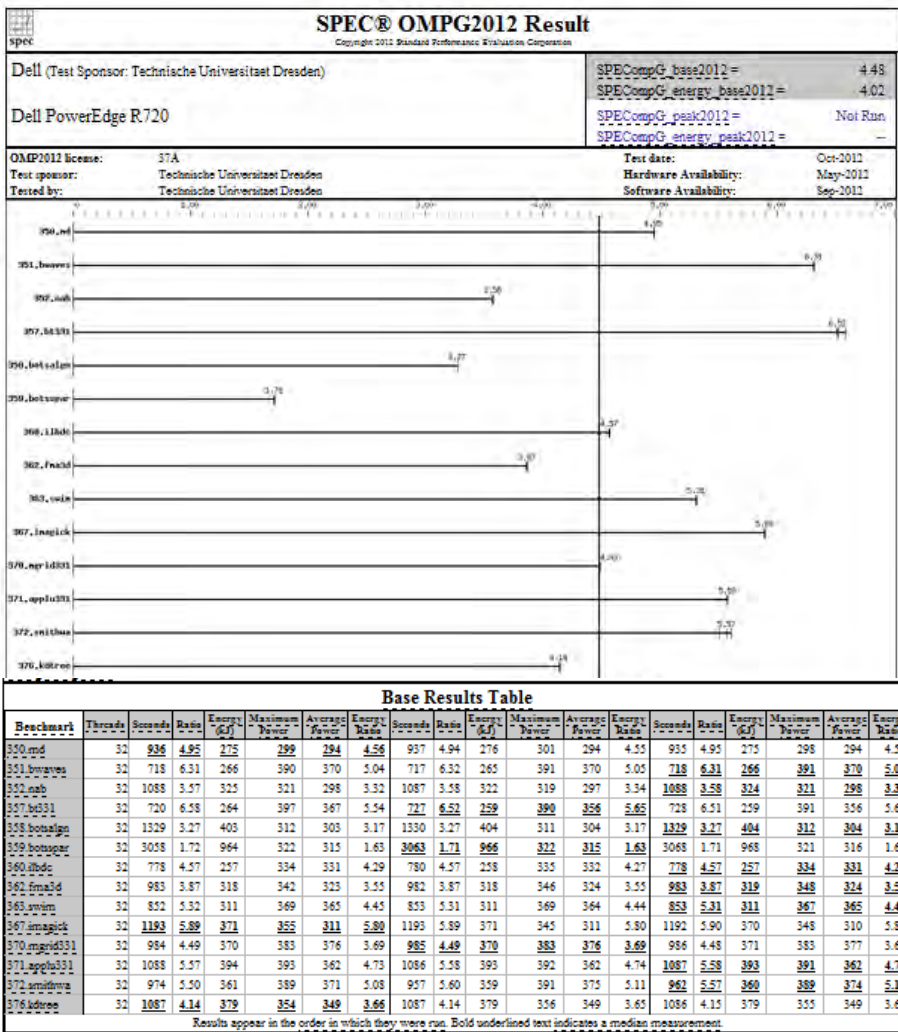
# SPECPOWER



Data from spec.org

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/>

# PERFORMANCE PER WATT FOR HPC



$$\epsilon = \frac{\text{Perf}}{\text{Watt}}$$

- 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*
- <http://eehpcwg.lbl.gov/>



THANK YOU  
FOR YOUR  
ATTENTION

Questions?