



# EE HPC WG TUE, a new look at PUE

Michael K Patterson, Intel

# ISC 2013 Best Paper Award

## TUE, a new energy-efficiency metric applied at ORNL's Jaguar

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**Abstract.** The recent, Power Usage Effectiveness (PUE), has been successful in improving energy efficiency of data centers, but it is not perfect. One challenge in that PUE does not account for the power distribution and cooling losses inside IT equipment. This is particularly problematic in the HPC (high performance computing) space where systems operators are moving cooling and power infrastructure out of the data center. This paper proposes two new metrics TUE (IT power usage effectiveness) similar to PUE but "inside" the IT and TUE (data-center usage effectiveness), which considers the rest for a total efficiency picture. We conclude with a demonstration of the method, and a case study of measurements at ORNL's Jaguar system. TUE provides a ratio of total energy (internal and external support energy costs) and the specific energy used in the HPC. TUE can also be a means for comparing HPC and non-HPC use.

**Keywords:** HPC, energy efficiency, metrics, data center

### 1 Introduction

This Whitepaper is a collaborative effort of the Metrics team of the Energy Efficient HPC Working Group (EEHPC WG). It reviews successes and issues with Power Usage Effectiveness (PUE) and explores some of the gaps in the metric. It discusses how the metric, applied the same simple logic to the IT, and then to the whole, including the IT and infrastructure. This methodology is shown to produce two new metrics, with the higher level metric being a combination of PUE and IT-power usage effectiveness (ITUE) yielding total-power usage effectiveness (TUE). These new metrics can be used to understand the same energy use from the utility to the silicon. It can reveal the same energy used and allow exploration of new trade-offs in the infrastructure or the IT use help design the total efficiency. Previously that total efficiency could neither be measured nor tracked without these proposed metrics.

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## GCS AWARD 2013

to

- Michael K. Patterson
- Stephen W. Poole
- Chung-Hsing Hsu
- Don Maxwell
- William Tschudi
- Henry Coles
- David J. Martínez
- Natalie Bates

for their outstanding scientific work

„TUE, a new energy-efficiency metric  
applied at ORNL's Jaguar“

Leipzig, June 27, 2013

Prof. Dr. Michael M. Resch  
Chairman of the International Award Committee  
Chairman of the GCS, GCS

Dr. Claus-Axel Müller  
Managing Director, GCS

This presentation adapted from our presentation at ISC 13...

*TUE, a new energy-efficiency metric applied at ORNL's Jaguar*

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Chung-Hsing Hsu  
Don Maxwell



William F Tschudi  
Henry Coles



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David J Martinez



Natalie J Bates

**EE HPC WG**

# Agenda

TUE Overview

Case Studies

ORNL

LLNL

LRZ

Japan's AIST (Advanced Industrial Science & Technology)

Where to now?

More Site Volunteers

# PUE

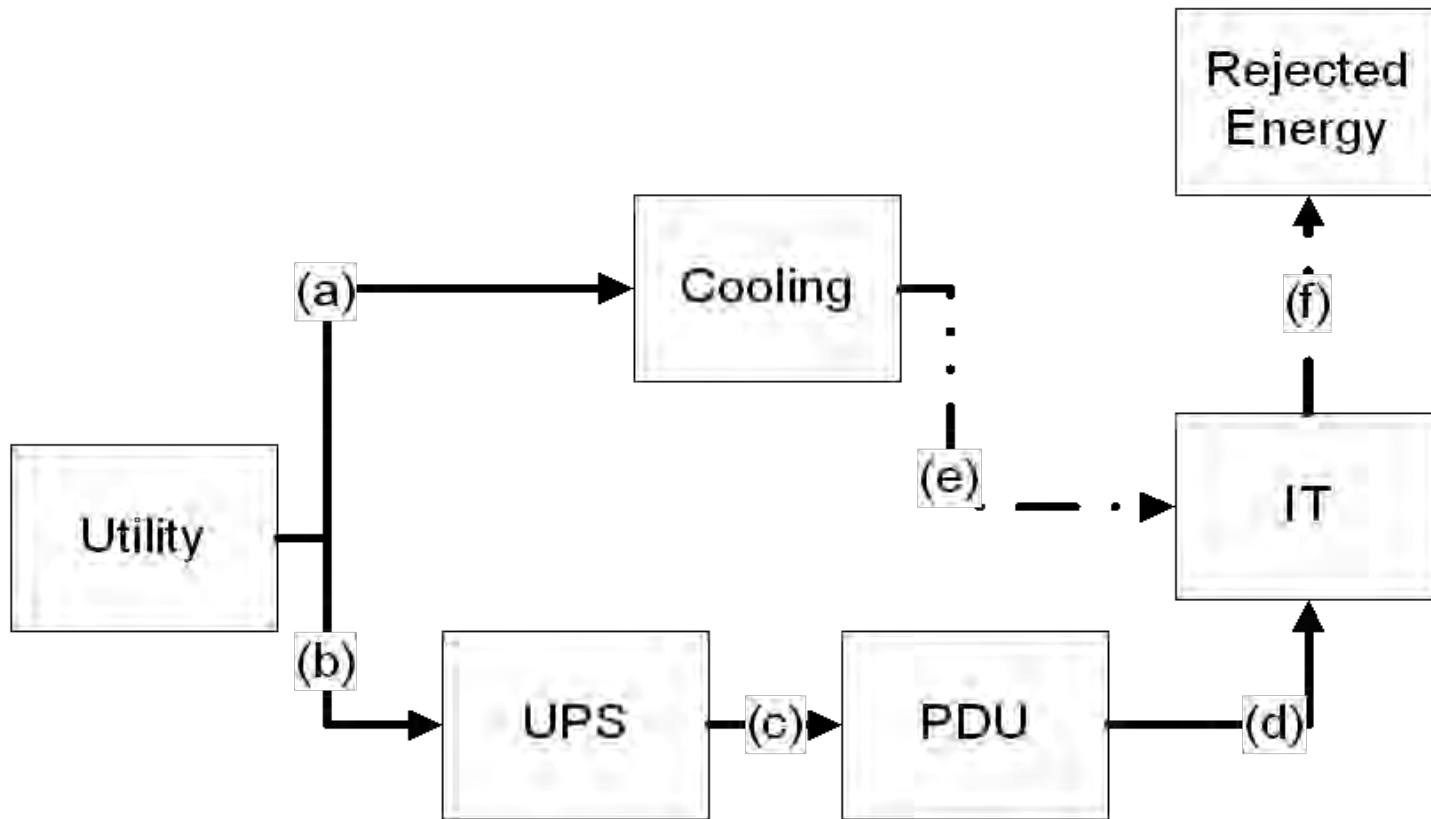
$$PUE = \frac{\textit{Total Data Center Annual Energy}}{\textit{Total IT Annual Energy}}$$

- Introduced in 2006 by Malone and Belady
- Developed and agreed to by EU Code of Conduct, DOE, EPA, Green Grid, ASHRAE, etc...
- Has led Energy Efficiency drive in Data Centers
  - PUE Average in 2007 ~ 2.5
  - Best in Class 2013:

NREL= 1.06, LRZ= 1.15, NCAR~1.2,

ORNL= 1.25, TU Dresden < 1.3

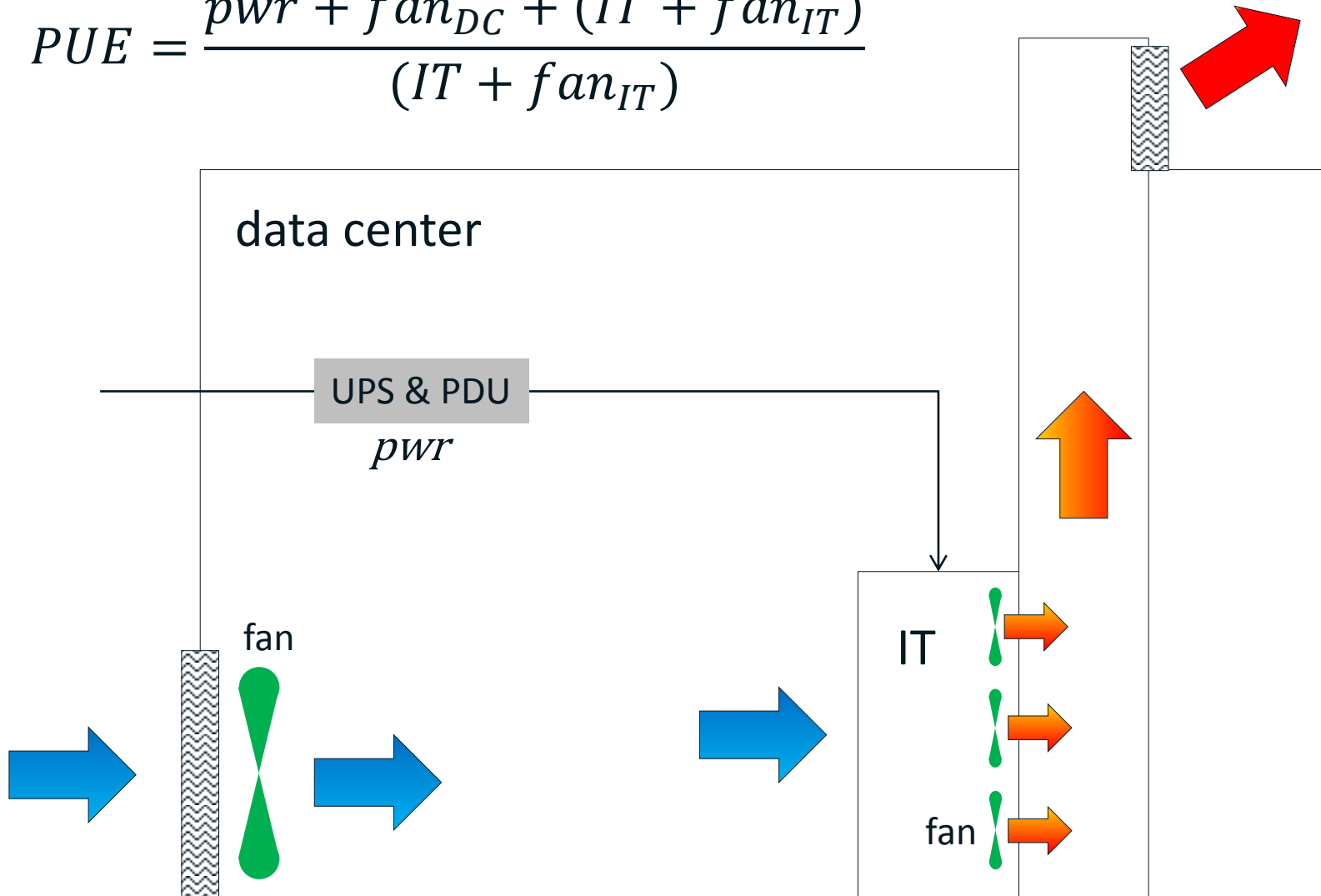
# PUE Definition



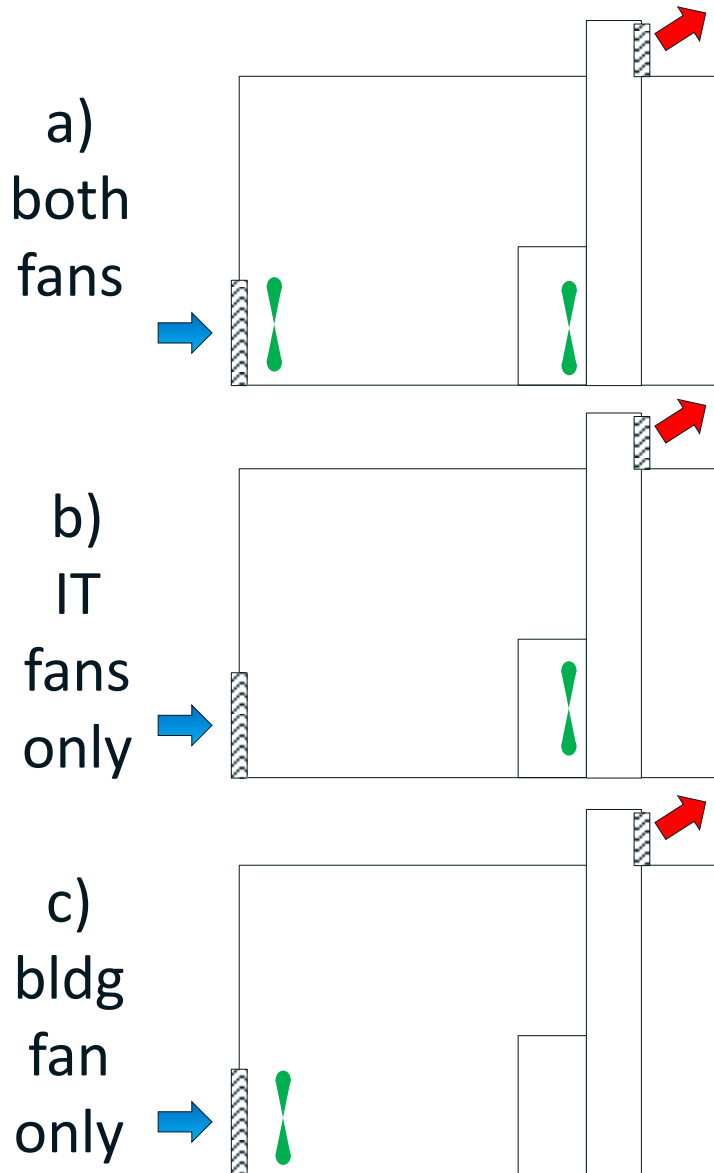
$$PUE = \frac{\text{Total Energy}}{\text{IT Energy}} = \frac{\text{Cooling} + \text{PowerDistribution} + \text{Misc} + \text{IT}}{\text{IT}} = \frac{a + b}{d}$$

but PUE isn't perfect, consider.....

$$PUE = \frac{pwr + fan_{DC} + (IT + fan_{IT})}{(IT + fan_{IT})}$$



# Three variations...



$$PUE_a = \frac{pwr + fan_{DC} + (IT + fan_{IT})}{(IT + fan_{IT})}$$

$$PUE_b = \frac{pwr + (IT + fan_{IT})}{(IT + fan_{IT})}$$

$$PUE_c = \frac{pwr + fan_{DC} + IT}{IT}$$

$PUE_b < PUE_a < PUE_c$  but is (b) best?  
We don't know....



# Can we define a “server-PUE”? Maybe ITUE?

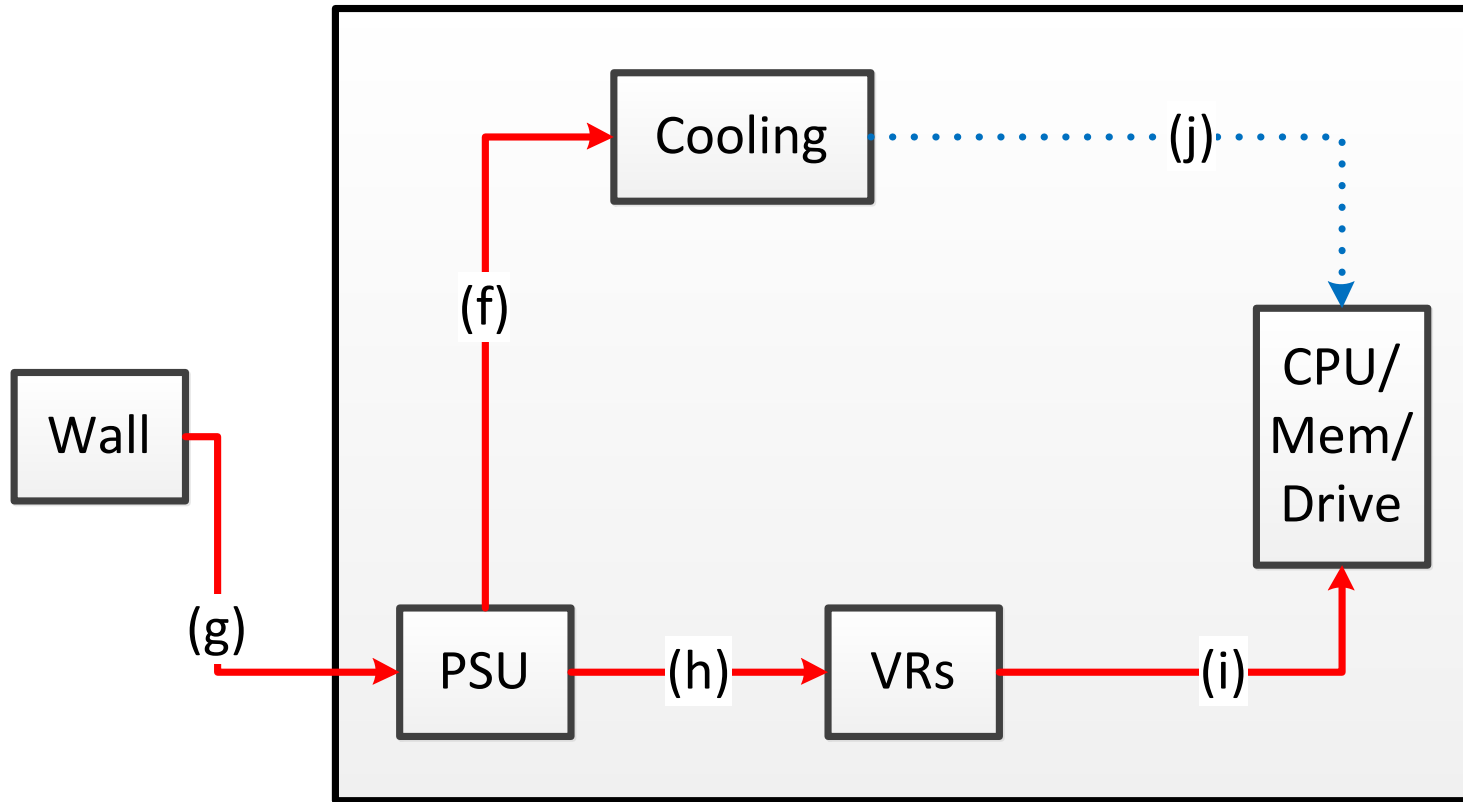
$$PUE = \frac{\text{Total Energy}}{\text{IT Energy}} = \frac{\text{Pwr} + \text{Cooling} + \text{Misc} + \text{IT}}{\text{IT}} = \frac{\text{Infrastructure Burden} + \text{IT}}{\text{IT}}$$

	Data Center	Server
Power dist losses	UPS, line losses, PDUs	PSU, VRs, board losses
Cooling losses	Chiller, CRAC, Pumps, Fans	Fans, Pumps
Misc losses	Security, Lighting, Building Control	Indicators, Platform Control
IT	Servers, Storage, Network	Processor, Memory, Disk

$$ITUE = \frac{\text{Infrastructure Burden} + \text{Compute}}{\text{Compute}} = \frac{\text{Pwr} + \text{Cooling} + \text{Misc} + \text{Compute}}{\text{Compute}}$$

$$ITUE = \frac{\text{Total Energy into the IT Equipment}}{\text{Total Energy into the Compute Components}}$$

# ITUE



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

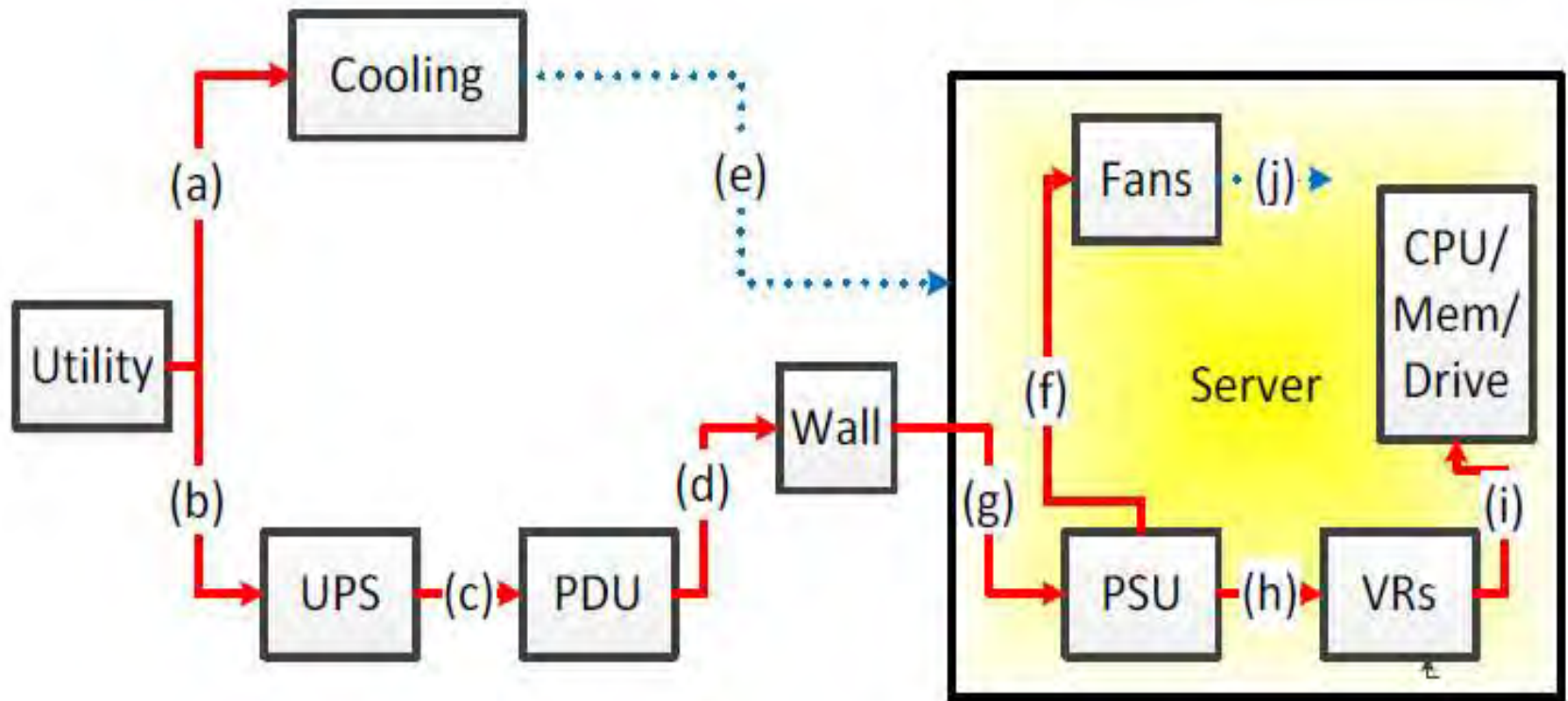
# The next step...

PUE and ITUE are both:

- dimensionless ratios
  - Represent the burden or “tax” of infrastructure
  - “1” is ideal, values larger than 1 are worse
  - Values less than 1 are not allowed
- 
- So why not:

$$TUE = PUE \times ITUE$$

# TUE

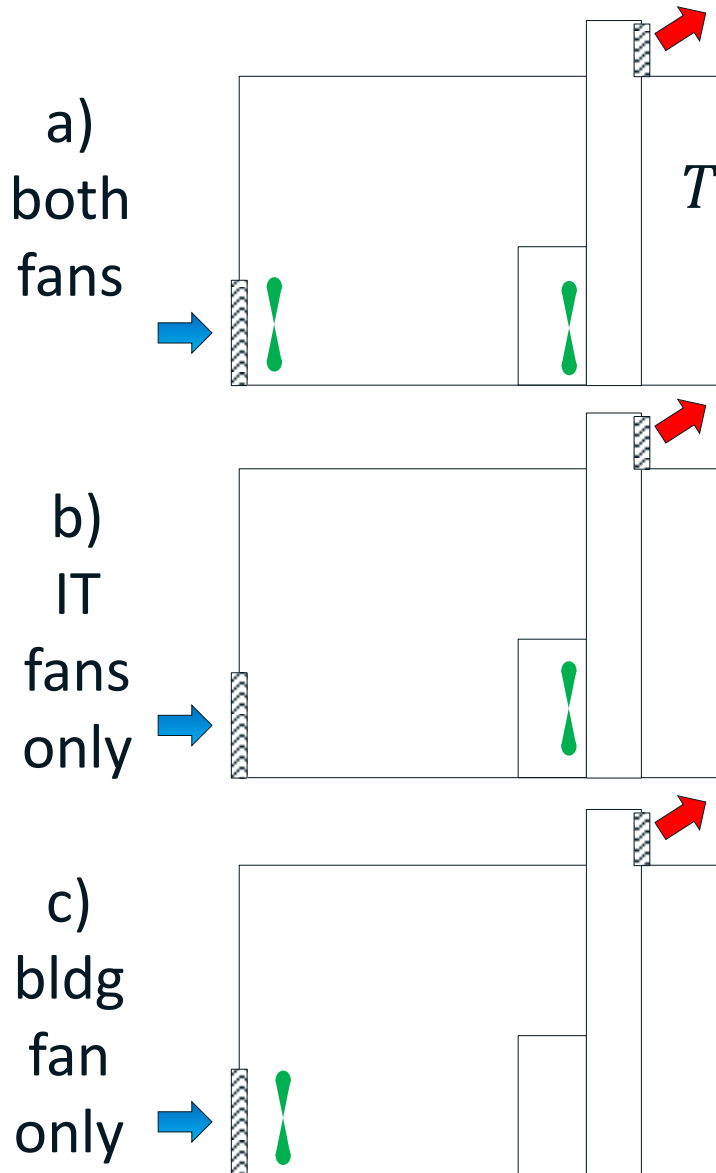


$$PUE = \frac{\text{Total Energy}}{\text{IT Energy}} = \frac{a + b}{d}$$

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

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

# Does it work?



$$TUE_a = \frac{pwr + fan_{DC} + fan_{IT} + compute}{compute}$$

$$TUE_b = \frac{pwr + fan_{IT} + compute}{compute}$$

$$TUE_c = \frac{pwr + fan_{DC} + compute}{compute}$$

The lowest TUE yields the lowest energy use. Yes, it works!

# Next Steps

New sites to work on TUE?

Features in new hardware?

Future Work

# Case Studies

ORNL

LLNL

LRZ

Japan's AIST (Advanced Industrial Science & Technology).

Thank You. Questions?





