PUE Baselining: Methods and Resources

Better Buildings Summit

May 27, 2015
Data Center Metering and Resource Guide

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Better Buildings Summit
Washington, DC
May 27, 2015
Agenda

• Definitions, including the Power Usage Effectiveness (PUE)
• Discussion of data center types
• Anticipated scenarios of metering systems and how they integrate with data center types
• Metering methods, including leveraging existing meters, starting from scratch
• Challenges to installing meters and gathering data
• Resources
Definitions

PUE
Power Usage Effectiveness

• The ratio of total energy use to that of the information technology (IT) equipment.

\[
PUE = \frac{\text{Total Data Center Facility Annual Energy Use}}{\text{IT Equipment Annual Energy Use}}
\]

• A measure of how efficiently the data center infrastructure uses energy.

• Three levels (1=Basic, 2=Intermediate, 3=Advanced)

• Focus on Level 1

What PUE is good for (infrastructure overhead)
Data Center Types  
1. Stand-alone

PUE = M1/M2
Data Center Types

2. Embedded

\[
PUE = \frac{(M4 + \text{data center cooling})}{M2}
\]
Data Center Types
2. Embedded, con’t

PUE calculation varies, depending on metering
Steps in Metering

1. Planning
   - Determine data center type
   - Determine existing metering
   - Review drawings
   - Interview staff/visit site
   - Decide on PUE calculation approach
Steps in Metering, con’t

2. Implementation
   - project initiation
   - defining needs and expectations
   - obtaining buy-in from all stakeholders
   - design (including review cycles)
   - installation
   - integration and configuration
   - Commissioning
     - end-to-end
     - sum-checking
   - training
Challenges to Meter Installation and Possible Solutions

• Electrical metering: Shut down one system at a time in N+x systems
• Electrical metering: Wait for system maintenance
• Thermal metering: Use hot-taps or ultrasonic meters
PUE level diagram

Simplified View

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

PUE Category 1
- Cooling Systems
- Chiller
- CRAC-CRAH

PUE Category 2
- UPS
- UPS Output KWH
- Main Dist Panel
- Maint. Bypass Panel
- PUE Category 1 Output of UPS (most commonly used)

PUE Category 3
- Power Dist Unit
- Step-Down X-Former
- Power to Rack PDUs
- Total Energy of IT Load at Rack or Device Level

Note:
- PUE Category 1-3 is based on annualized energy (KWH).
- PUE Category 0 is based on PEAK Power KW see notes for details.

Graphic Courtesy of NAAI, Inc.
Resources

• Data Center Metering and Resource Guide:

• PUE: a Comprehensive Examination of the Metric:

• Center of Expertise for Energy Efficiency in Data Centers:
  https://datacenters.lbl.gov/

• Data Center Energy Practitioner (DCEP) Program:
  https://datacenters.lbl.gov/dcep
Questions?

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Approaches to PUE at the Lawrence Berkeley National Lab: Three Case Studies

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Examples of getting to PUE at LBNL data centers

- Building 50A-1156: the hodgepodge
- Building 50B-1275: the case-study king
- Building 59: the many-megawatt supercomputer center
LBNL site map
Lawrence Berkeley National Laboratory
Room 50A-1156: “the hodge-podge”

- decades old, embedded data center in office building
- 2450 square feet
- ~100 kW IT load
- shared AHU for primary cooling on house chilled water
- standby CRAC with remote air-cooled condenser
- 2’ raised floor
- combination of telecom, house services, and high-performance computing
- mix of UPS and direct power distribution
Approach to PUE:

- Level 1
- Measured IT
- Data center is embedded with multiple power and cooling feeds
- There are some existing meters on IT loads
- Identify meter additions needed
- Triage based on cost vs. effect on PUE
- Implement changes
- Calculation will use IT load and estimate HVAC based on system ratings and one-time readings
Lawrence Berkeley National Laboratory
Room 50B-1275 “the case-study king”

45-year-old data center
5600 square feet
~450 kW IT load
7 CRACs 15 to 30 tons of cooling each in 2-4 stages
Down-flow units (raised floor)
Water-cooled
Other cooling including rear doors, enclosed racks, AHU

Numerous case studies
LBNL Room 50B-1275

IT Computing Facilities 5600 sq ft – Raised floor; 7 CRACs
Approach to PUE:

- Level 2 (transformer losses measured or estimated)
- Measured IT, HVAC, lighting
- Data center is embedded and has multiple power and cooling feeds
- PUE is already tracked in real time (~1.4) using numerous meters
- Metering needs update to reflect changes in power and cooling
- Identify meter additions, deletions, and moves needed
- Triage based on cost vs. effect on PUE
- Implement changes
LBNL Room 50B-1275, con’t

Electric metering
LBNL Room 50B-1275, con’t

Thermal metering
Lawrence Berkeley National Laboratory
Building 59: the Computational Research and Theory Facility
“the multi-megawatt supercomputer center”

- Brand-new supercomputer center, embedded
- 142,000 square feet total
- 7 MW IT load to start, then up to 17, then ???
- IT load will dominate building
- 2 large AHUs for air-cooled loads
- 4 cooling towers with heat exchangers for water-cooled loads
- Water-cooled supercomputers
- Air and water side economizers
- Air-side heat recovery for heating offices
- IT loads cooled without compressors
LBNL Building 59
Approach to PUE:

- Level 2 (PDU outputs for IT)
- Measured IT, HVAC, lighting
- Data center is embedded with multiple power and cooling feeds
- PUE will be tracked in real time (~1.06) using hundreds of meters
- Meter location, accuracy, and reporting capability in review and commissioning
- Identify meter additions needed
- Triage based on cost vs. effect on PUE
- Implement changes
Lawrence Berkeley National Laboratory
Building 59, con’t
Conclusions: PUE determination at LBNL

- Is case-by-case—every center is different
- Takes advantage of existing meters
- Minimizes estimation
- Typically involves numerous meters to resolve energy flow in embedded spaces
Questions?

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Metering for PUE

Steve Hammond   May 2015
NREL – Two Data Center Use Cases

RSF - Enterprise Air Cooled
• Fully contained hot aisle
  • Server fans pull cold air into servers and exhaust heat to hot aisle.
• 1.1-1.2 PUE Winter, Spring, Fall
• 1.2-1.4 PUE Summer
• Waste heat used to heat building
• Economizer and Evaporative cooling
• Low fan energy design
• ~200kW, ~2,000 Sq Ft.

ESIF – HPC Liquid Cooled Data Center
• 95% of IT heat load directly to liquid.
• 1 fully contained hot aisle for lower power, low density air cooled equipment.
• Annualized average PUE 1.06
• Waste heat used to heat building
• Evaporative cooling
• VFD motors, Low fan energy design
• 10MW, 10,000 Sq Ft.

http://www.nrel.gov/docs/fy12osti/52785.pdf
RSF Enterprise “Air Cooled” Data Center
RSF Enterprise “Air Cooled” Data Center

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
<th>Hours per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dehumidification</td>
<td>for hours when the outdoor air was more humid than the acceptable supply air criteria. Some form of mechanical cooling or dehumidification would be required for these hours.</td>
<td>44 hours/year</td>
</tr>
<tr>
<td>Economizer</td>
<td>for hours when the outdoor air can satisfy the supply air criteria with no additional conditioning</td>
<td>559 hours/year</td>
</tr>
<tr>
<td>Evaporative Cooling</td>
<td>for hours when adiabatic humidification/cooling (70% effectiveness) of outside air can meet the supply air criteria</td>
<td>984 hours/year</td>
</tr>
<tr>
<td>Mixing</td>
<td>for hours when the outside air can be mixed with hot aisle air to meet the supply air criteria</td>
<td>1063 hours/year</td>
</tr>
<tr>
<td>Mixing and Humidification</td>
<td>When the outside air is cool and dry, outdoor air can be mixed with hot aisle air, then adiabatically humidified to the supply air criteria.</td>
<td>6110 hours/year</td>
</tr>
</tbody>
</table>
PUE Metering—simple & effective

\[
PUE = \frac{Total\ Energy}{IT\ Energy} = \frac{Cooling + PowerDistribution + Misc + IT}{IT} = \frac{a + b}{d}
\]
Air Cooled Data Center PUE

6 week data: mid-November to end of December
NREL ESIF Liquid Cooled Data Center

Showcase Facility
- ESIF 182,000 s.f. research facility
- Includes 10MW, 10,000 s.f. data center
- LEED Platinum Facility, PUE 1.06
- NO mechanical cooling (*eliminates expensive and inefficient chillers*).
- Use evaporative cooling only.

Data Center Features
- Direct, component-level liquid cooling (75F cooling water).
- 95-110F return water (waste heat), captured and used to heat offices and lab space.
- Pumps more efficient than fans.
- High voltage 480VAC power distribution directly to compute racks (*improves efficiency, eliminates conversions*).

*Compared to a typical data center:*
- Lower CapEx – cost less to build
- Lower OpEx – efficiencies save ~$1M per year in operational expenses.

Integrated “chips to bricks” approach.

Utilize the bytes and the BTUs!
Key HPC Data Center Specs

• Warm water cooling, 24C (75F)
  • ASHRAE “W2” category
  • Water much better working fluid than air - pumps trump fans.
  • Utilize high quality waste heat, +35C (95F).
  • +95% IT heat load to liquid.

• Racks of legacy equipment
  • Up to 10% IT heat load to air.

• High power distribution
  • 480VAC, Eliminate conversions.

• Think outside the box
  • Don’t be satisfied with an energy efficient data center nestled on campus surrounded by inefficient laboratory and office buildings.
  • Innovate, integrate, optimize.
Direct Liquid Cooling & Energy Recovery On Display

“We want the bytes AND the BTU’s!”

NREL-ESIF Data Center
Energy Recovery at 1 MW IT Load

Energy Targets
PUE 1.06
EUE 0.9

Current Design
PUE 1.05
EUE 0.7

Steve Hammond
ESIF HPC Datacenter PUE Calculation

NREL ESIF – DATA CENTER ENERGY EFFICIENCY METRICS

POWER USE EFFECTIVENESS (PUE)
- DATA CENTER ENERGY EFFICIENCY is benchmarked using an industry standard metric of POWER USE EFFECTIVENESS (PUE). This PUE is defined as follows:
  
  \[
  \text{PUE} = \frac{\text{TOTAL FACILITY POWER}}{\text{IT EQUIPMENT POWER}}
  \]

ENERGY USE EFFECTIVENESS (EUE) is a metric of recovered energy beneficially used outside of the data center (heating). The EUE is defined as follows:

\[
\text{EUE} = \frac{\text{TOTAL FACILITY POWER}}{\text{TOTAL FACILITY ENERGY}} - \frac{\text{IT EQUIPMENT ENERGY}}{\text{TOTAL FACILITY ENERGY}}
\]

1. **Lighting & Plug Power**
   - Calculated power based on run time hours (typical)
   - Data center electrical transformer

2. **Normal Load**
   - Data center normal power service entrance switchboard

3. **Stand-by Power**
   - Data center electrical transformer

4. **Central Plant Distribution Board DSB-CP**

5. **Central Plant Electrical Emergency Distribution Board, DSB-CPE**

6. **Central Plant Emergency Distribution Board, DSB-USB**

7. **Mechanical Distribution Board, DSB-MB1**

8. **U.S. Distribution Board, ATP-U2SB**

9. **H.P. Distribution Board, ATP-H2SB**

10. **Power Distribution Unit, DPU-1**

11. **Power Distribution Unit, DPU-2**

12. **Power Distribution Unit, DPU-3**

13. **Energy Recovery Pumps, Panel X, Y, Z**

14. **IT Equipment Power**

15. **Cooling Distribution Rack, CDU-1**

16. **Cooling Distribution Rack, CDU-2**

17. **Cooling Distribution Rack, CDU-3**

18. **Cooling Distribution Rack, CDU-4**

19. **Cooling Distribution Rack, CDU-5**

20. **Cooling Distribution Rack, CDU-6**


22. **Recovered Energy** (Typical for HPC Racks)
Initial HPC Datacenter PUE metering*

POWER USE EFFECTIVENESS (PUE)
DATA CENTER ENERGY EFFICIENCY IS BENCHMARKED USING AN INDUSTRY STANDARD METRIC OF POWER USE EFFECTIVENESS (PUE). THE PUE IS DEFINED AS FOLLOWS:

POWER USE EFFECTIVENESS = TOTAL FACILITY POWER
IT EQUIPMENT POWER

TOTAL FACILITY POWER = LIGHTING & PLUG POWER + COOLING LOADS + PUMP LOADS + HVAC LOADS + IT EQUIPMENT POWER

IT EQUIPMENT POWER = TOTAL POWER USED TO MANAGE, PROCESS, STORE, OR ROUTE DATA WITHIN THE DATA CENTER

\[
\frac{6 + 2 + 34 + 7 + 636}{636} = 1.077
\]

*Very first meter readings, November 2013.
Questions?