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**A River of Energy Solutions**

# **NREL Research Support Facility Data Center Case Study**

**Otto Van Geet, PE,  
National Renewable Energy Laboratory**

# DOE/NREL Research Support Facility: Project Goals

- More than 800 people in DOE office space on NREL's campus
- 220,000 ft<sup>2</sup>
- Design/build process with required energy goals
  - 25 kBtu/ft<sup>2</sup>
  - 50% energy savings
  - LEED Platinum
- Replicable
  - Process
  - Technologies
  - Cost
- Site, source, carbon, cost ZEB:B
  - Includes plugs loads and datacenter
- Firm fixed price of ~\$64 million
  - \$259/ft<sup>2</sup> construction cost (not including \$27/ft<sup>2</sup> for PV from PPA/ARRA)
- Open first phase June 10, 2010

Credit: Haselden Construction



# RSF Net-Zero Boundary



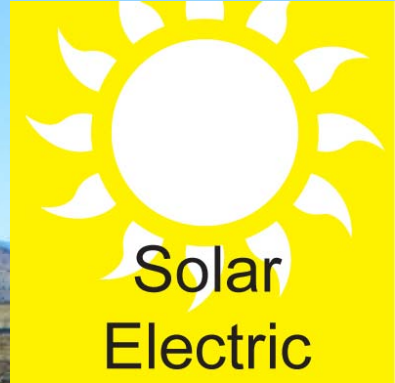
RSF Staff  
Parking Garage

RSF II

RSF I

RSF Visitor  
Parking Lot

# Photovoltaic System



1,156 KW

449 KW

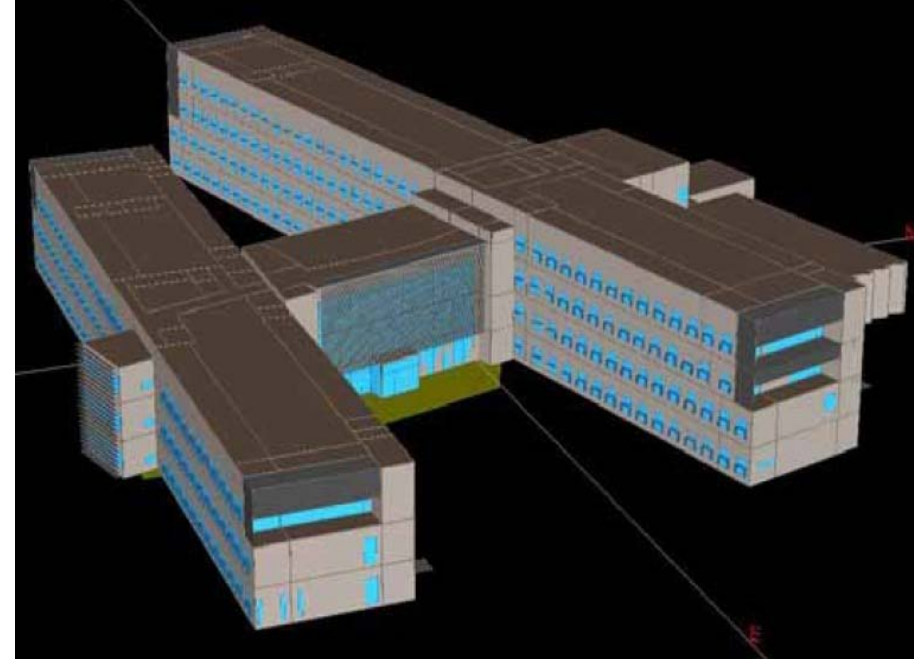
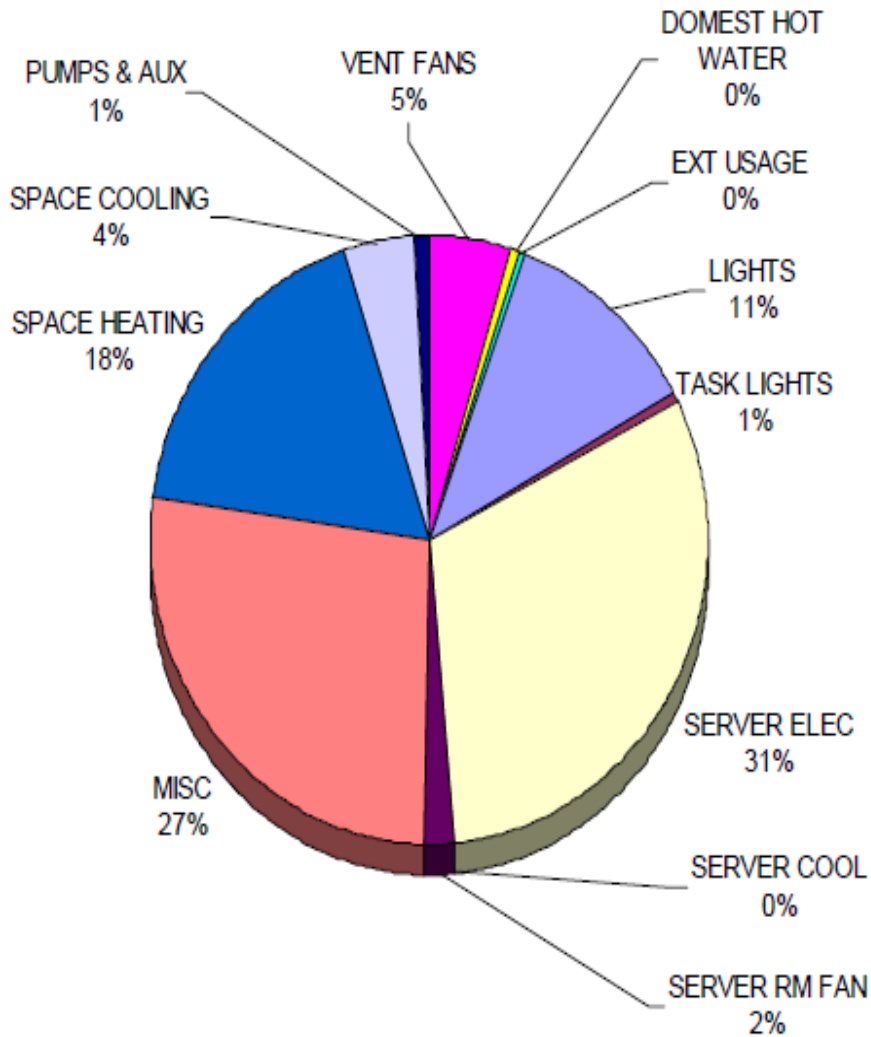
408 KW

524 KW

- Power Purchase Agreement (PPA) provides full rooftop array on RSF 1
- Zero energy = building, parking lot and future parking garage arrays (2537 kW)

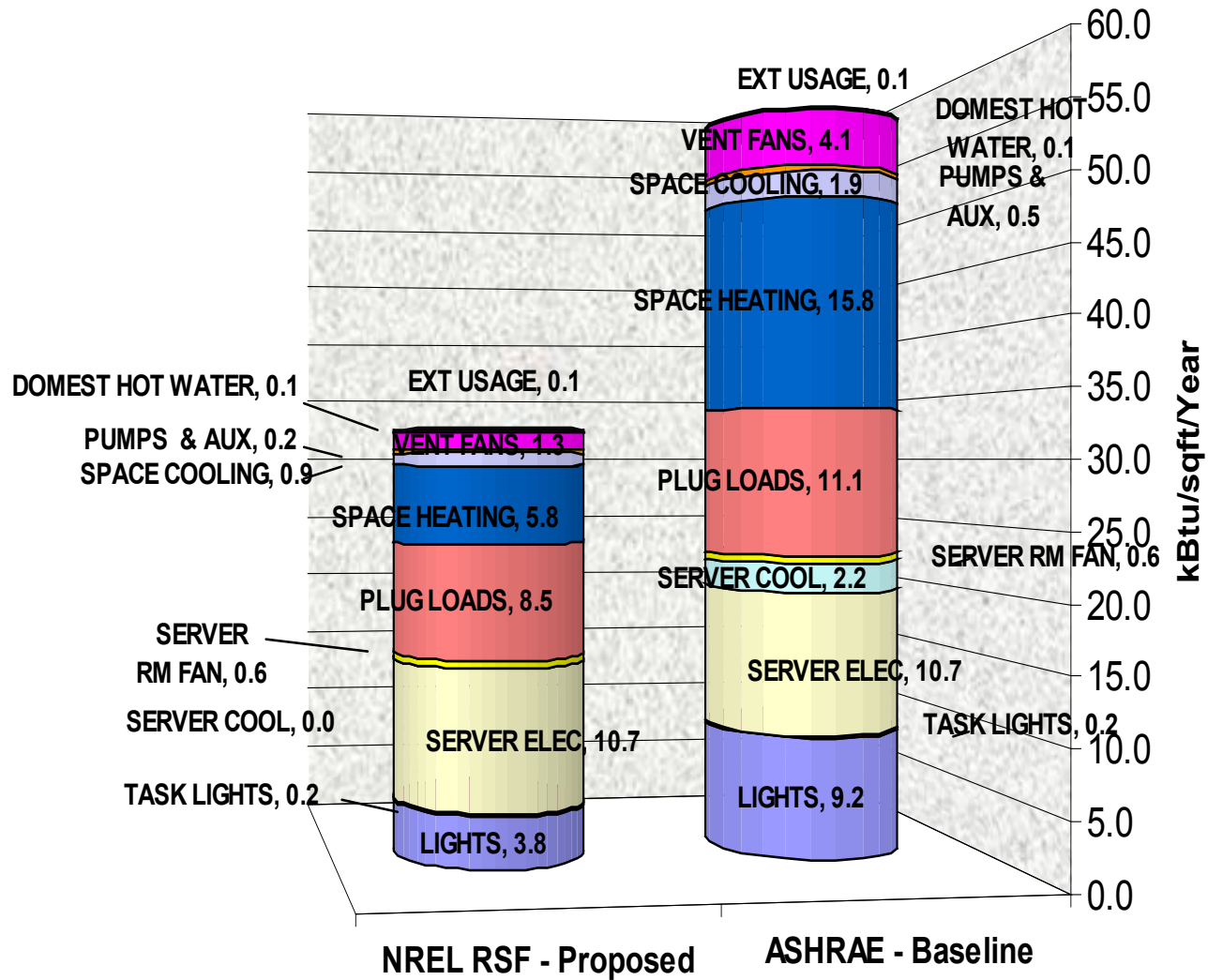
# Energy Modeling

NREL RSF Energy Use Breakdown



End Use	kBtu/ft2
Lights	3.85
Task Lights	0.19
Data Center	10.60
Data Center Cooling	0.01
Data Center Fans	0.55
Office Plug Loads	9.16
Space Heating	6.11
Space Cooling	1.42
Pumps	0.27
Ventilation Fans	1.61
Domestic Hot Water	0.13
Exterior Lights	0.12

# NREL RSF Annual Energy Consumption Comparison



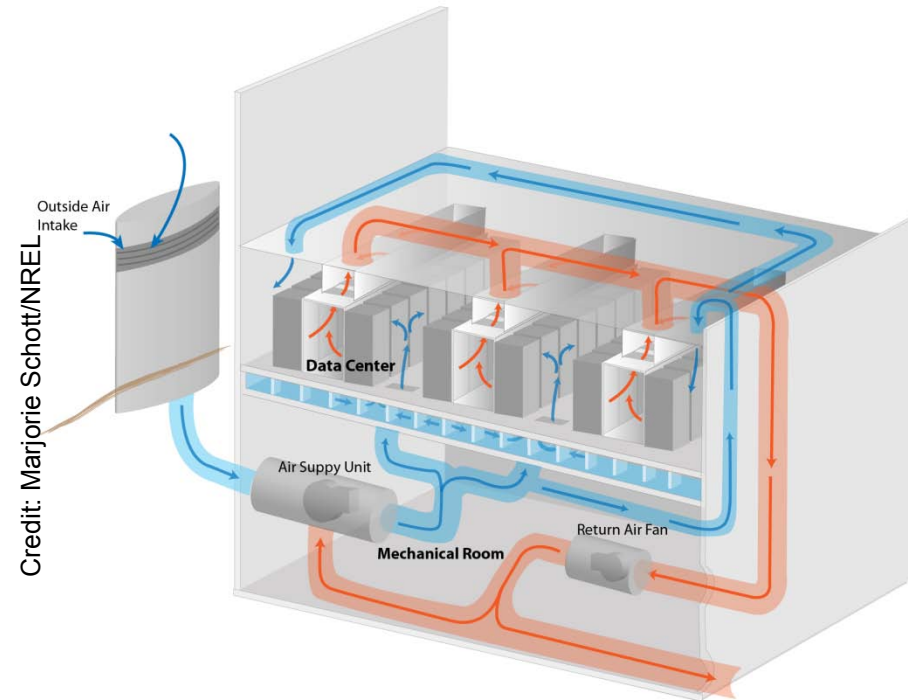
- LIGHTS
- TASK LIGHTS
- SERVER RM FAN
- PLUG LOADS
- PUMPS & AUX
- SERVER ELEC
- SPACE HEATING
- SPACE COOLING
- VENT FANS
- DOMEST HOT WATER
- SERVER COOL
- EXT USAGE

# RSF Data Center



# Datacenter

- Fully containing hot aisle
  - Custom aisle floor and door seals
  - Ensure equipment designed for cold aisle containment
    - And installed to pull cold air
      - Not hot air...
- 1.1-1.2 PUE Winter, Spring, Fall
- 1.2-1.4 PUE Summer
- control hot aisle based on return temperature of ~90F
- Waste heat used to heat building
- Economizer and Evaporative cooling
- Low fan energy design
- 1900 Sq Ft.





# Data center

Dehumidification	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.	44 hours/year
Economizer	for hours when the outdoor air can satisfy the supply air criteria with no additional conditioning	559 hours/year
Evaporative Cooling	for hours when adiabatic humidification/cooling (70% effectiveness) of outside air can meet the supply air criteria	984 hours/year
Mixing	for hours when the outside air can be mixed with hot aisle air to meet the supply air criteria	1063 hours/year
Mixing and Humidification	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.	6110 hours/year

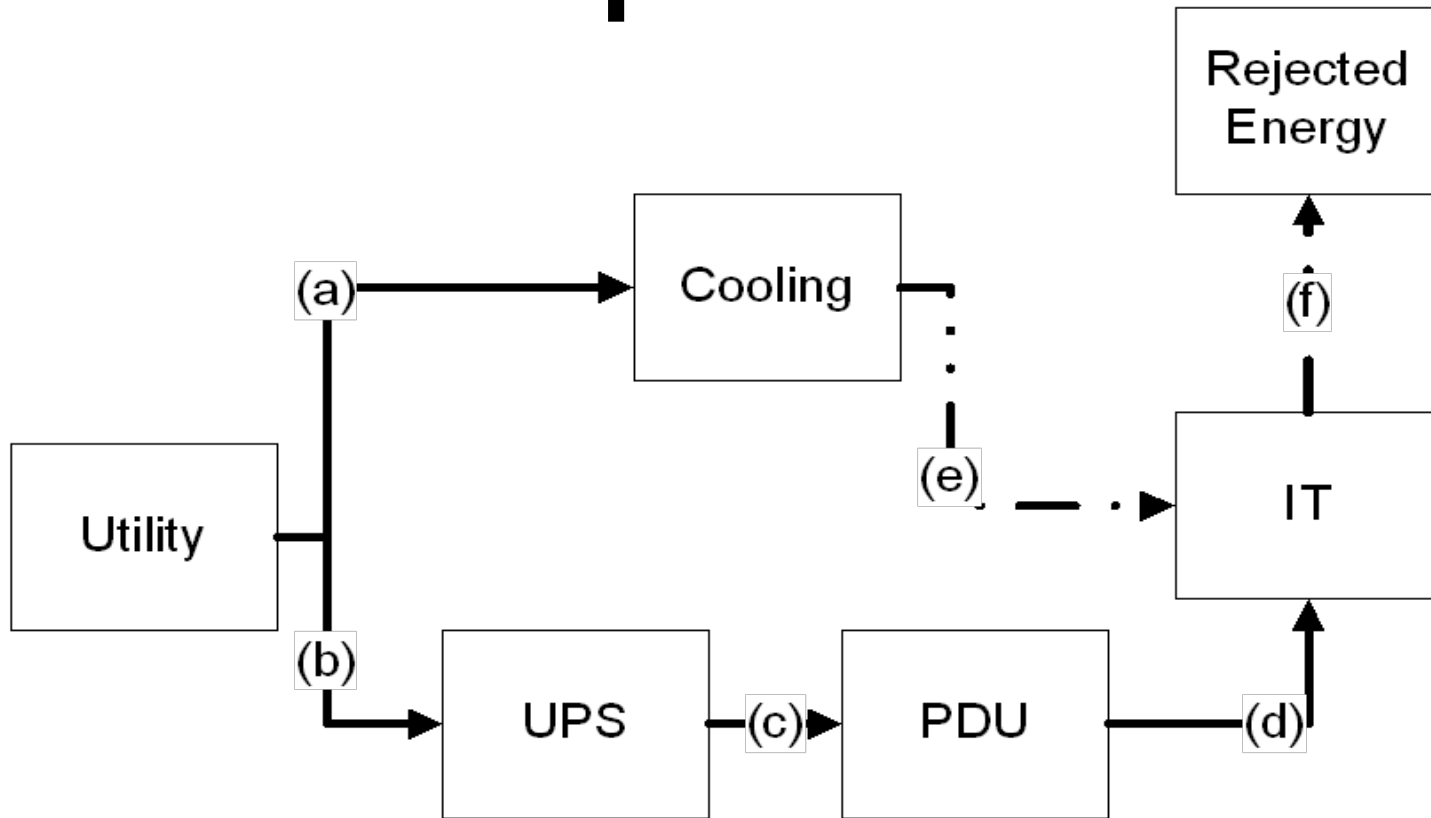
# Power Usage Effectiveness (PUE)

$$\text{PUE} = \frac{\text{Total Facility Power}}{\text{IT Equipment Power}}$$

**Total Facility Power Consists of:**

- **IT Equipment Power**
- **Mechanical Cooling**
- **Lighting**
- **Electrical Line Loss & Conversion**

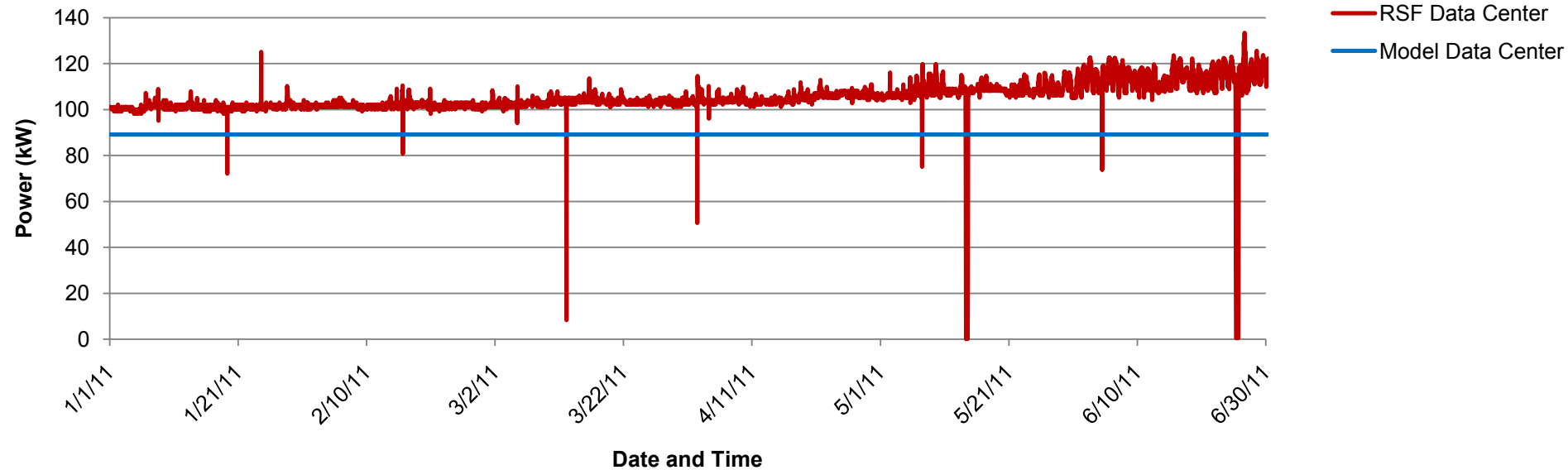
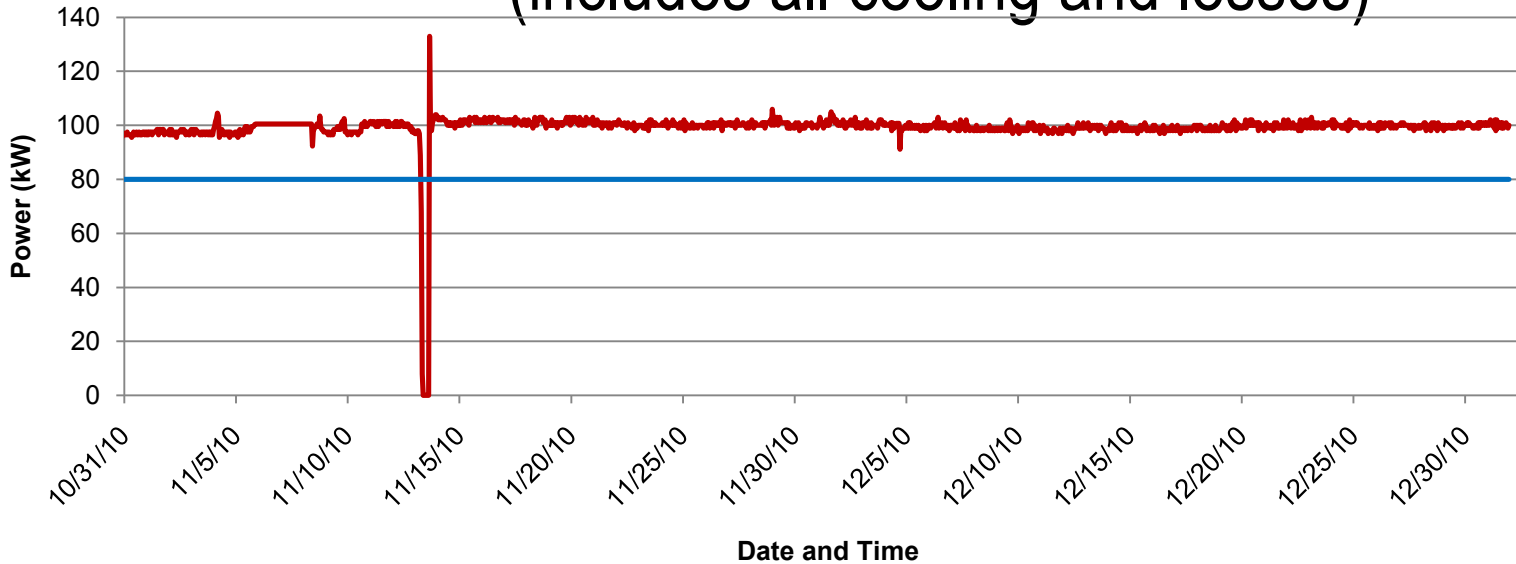
# PUE – simple and effective



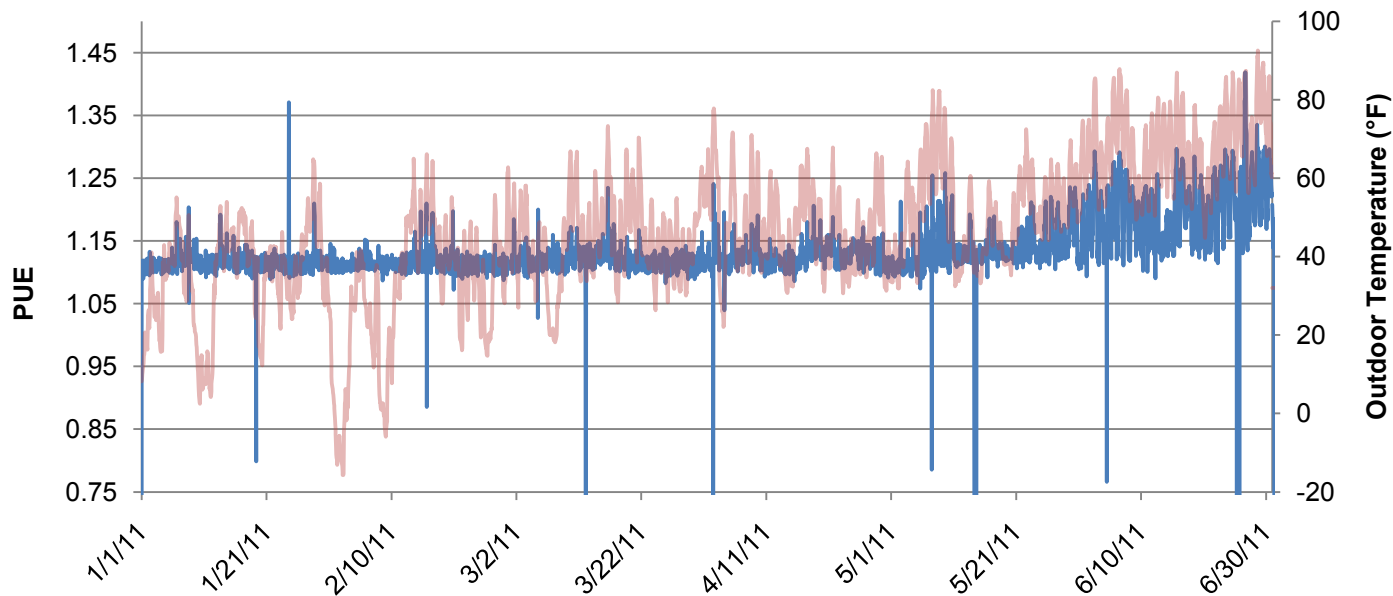
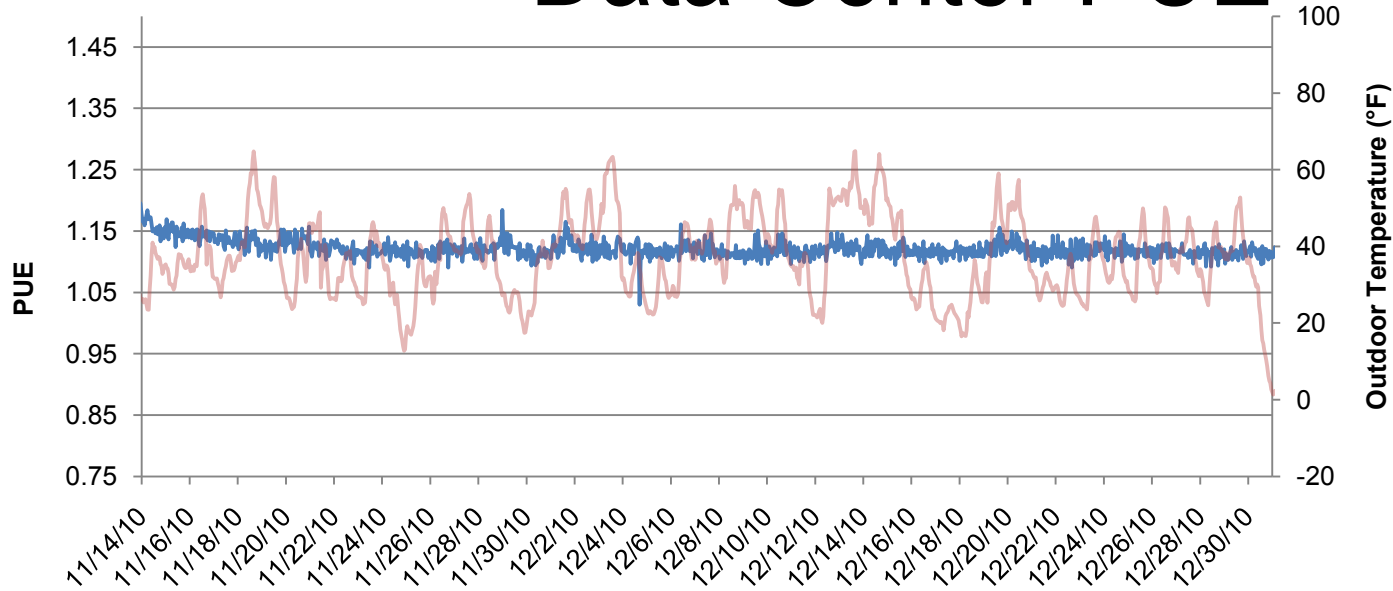
$$PUE = \frac{\text{Total Energy}}{\text{IT Energy}} = \frac{\text{Cooling} + \text{PowerDistribution} + \text{Misc} + \text{IT}}{\text{IT}} = \frac{a + b}{d}$$

# Total Data Center Power

(includes all cooling and losses)



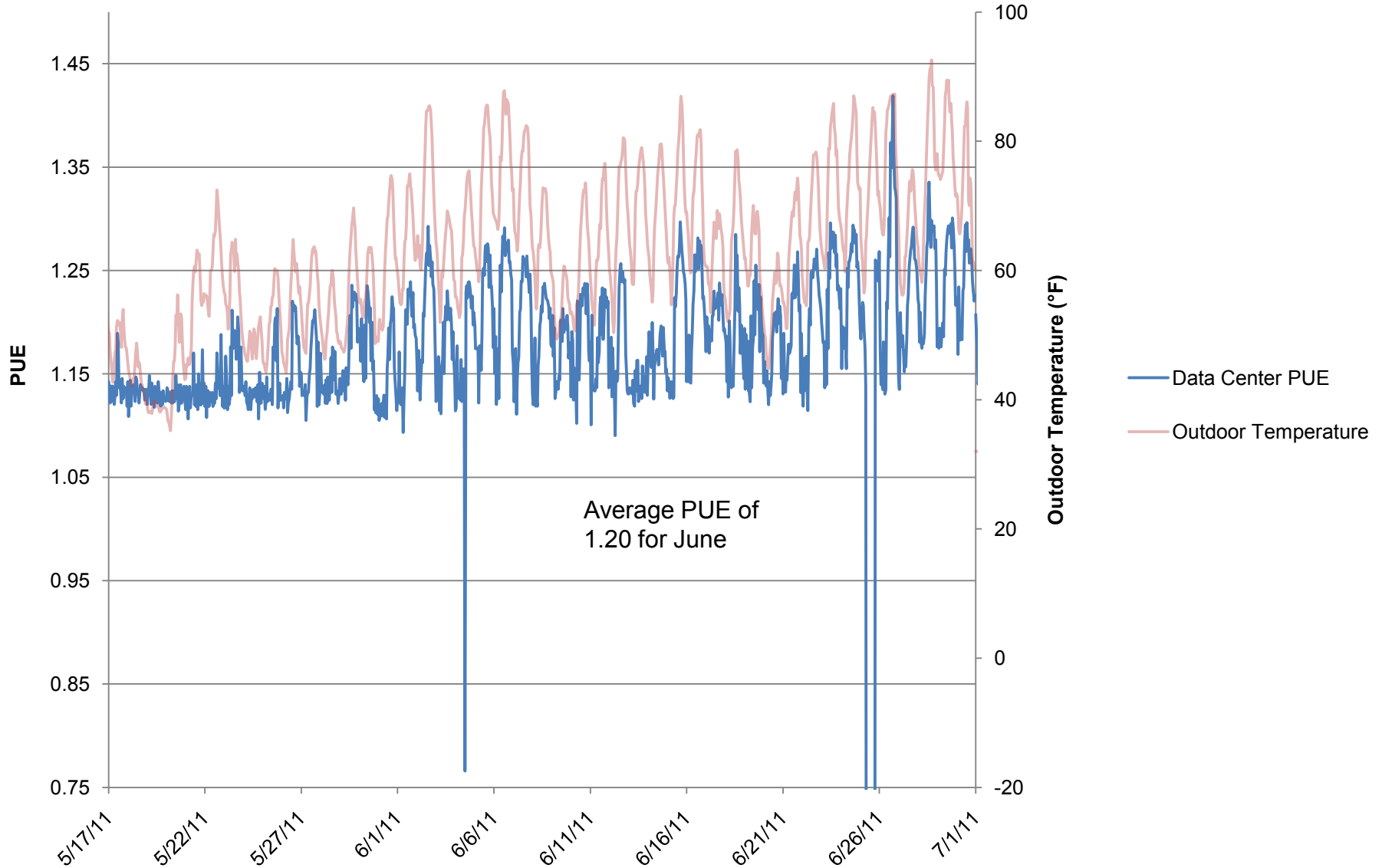
# Data Center PUE



- Data Center PUE
- Outdoor Temperature

# Data Center PUE

Elevated outdoor temperatures have increased cooling energy and PUE



**“I am re-using waste heat from my data center on another part of my site and my PUE is 0.8!”**

“I am re-using waste heat from my data center in another part of my site and my PUE is 0.8!”



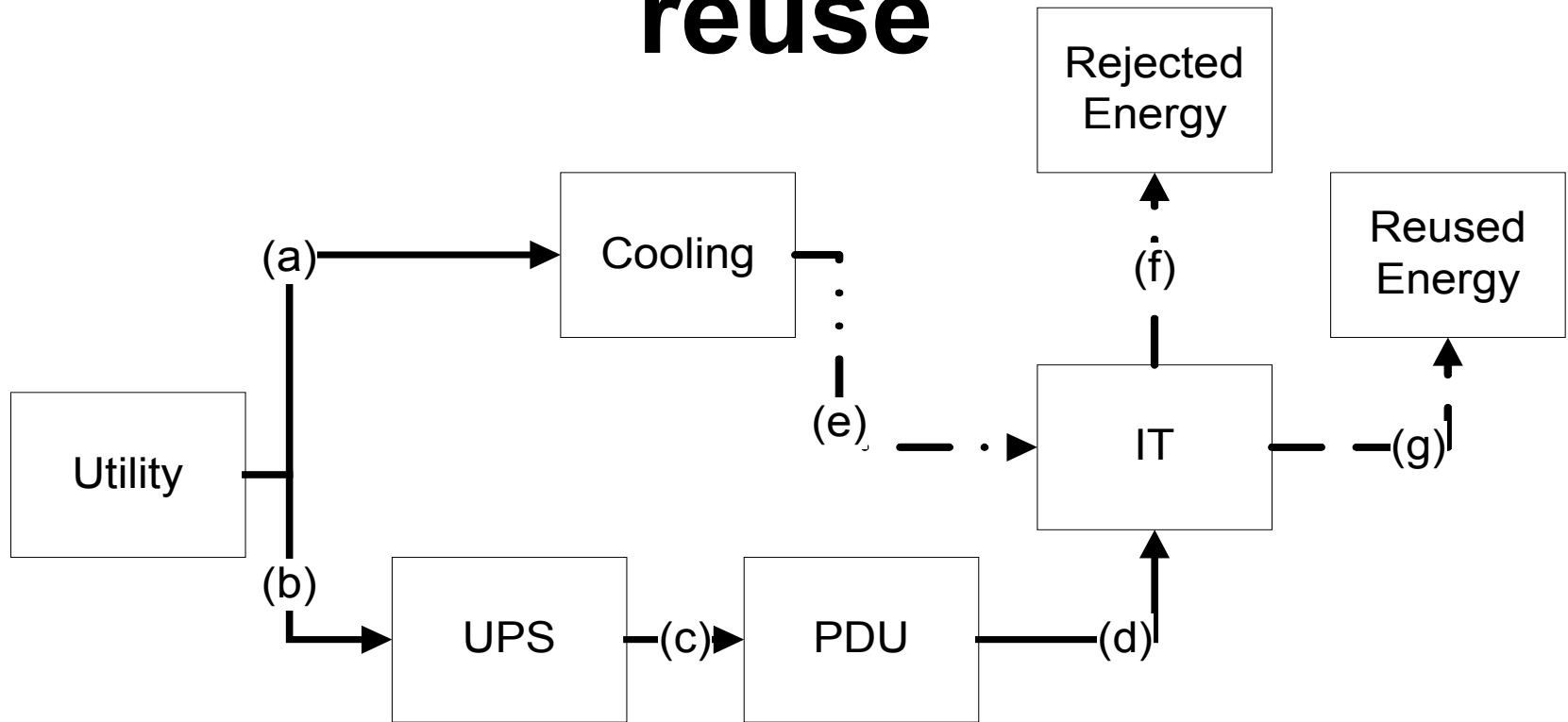
**ASHRAE & friends (DOE, EPA, TGG, 7x24, etc..) do not allow reused energy in PUE (Joint White Paper just released) & PUE is always  $>1.0$**

**Another metric has been developed by The Green Grid; ERE – Energy Reuse Effectiveness**

<http://www.thegreengrid.org/en/Global/Content/white-papers/ERE>



# ERE – adds energy reuse



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

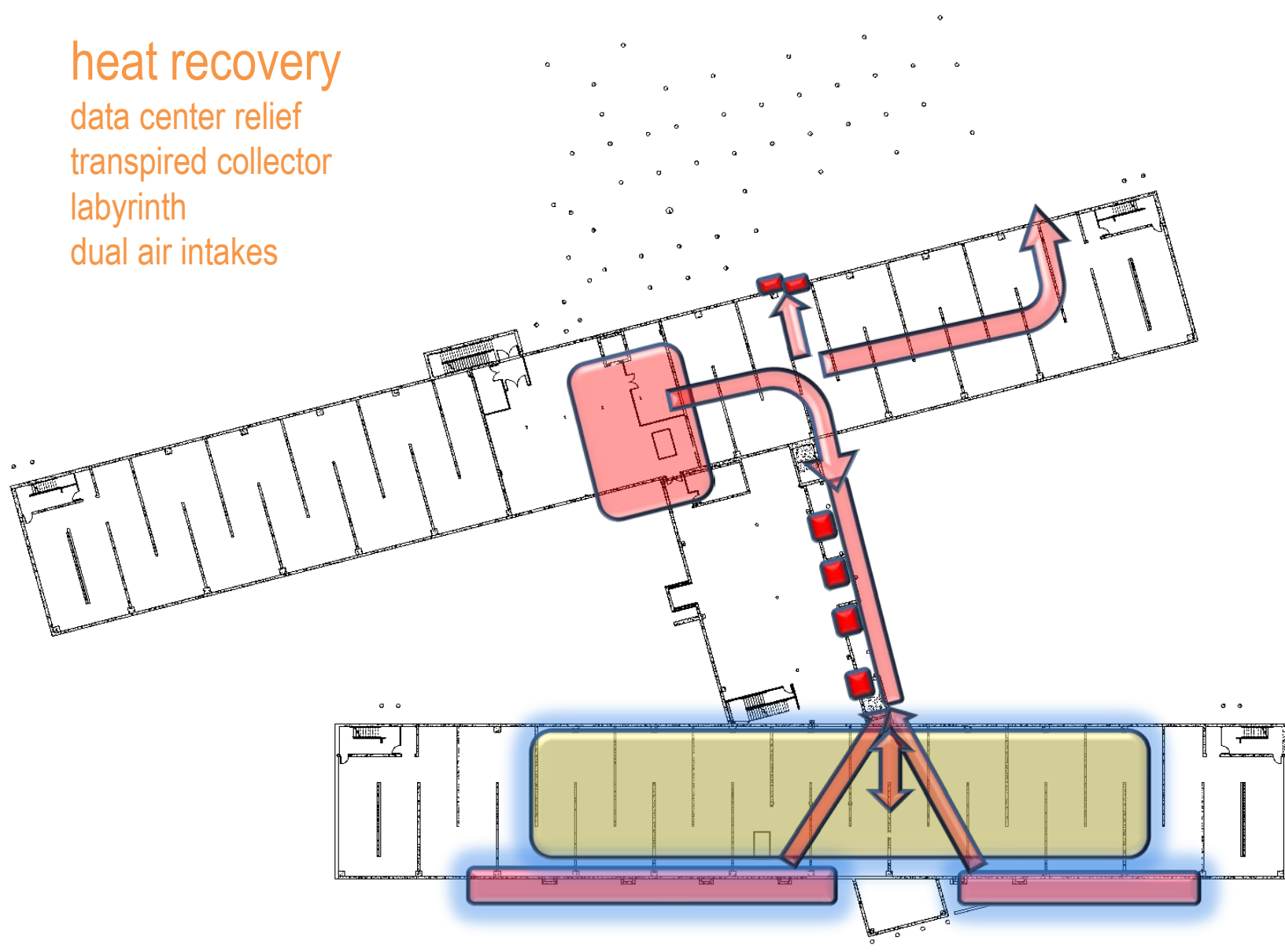
$$= \frac{\text{Cooling} + \text{PowerDistribution} + \text{Misc} + \text{IT} - \text{Reuse}}{\text{IT}} = \frac{a + b - g}{d}$$

# PUE and ERE Ranges

$$1 \leq PUE \leq \infty \quad PUE = \frac{\text{Cooling} + \text{Power} + \text{Lighting} + IT}{IT}$$

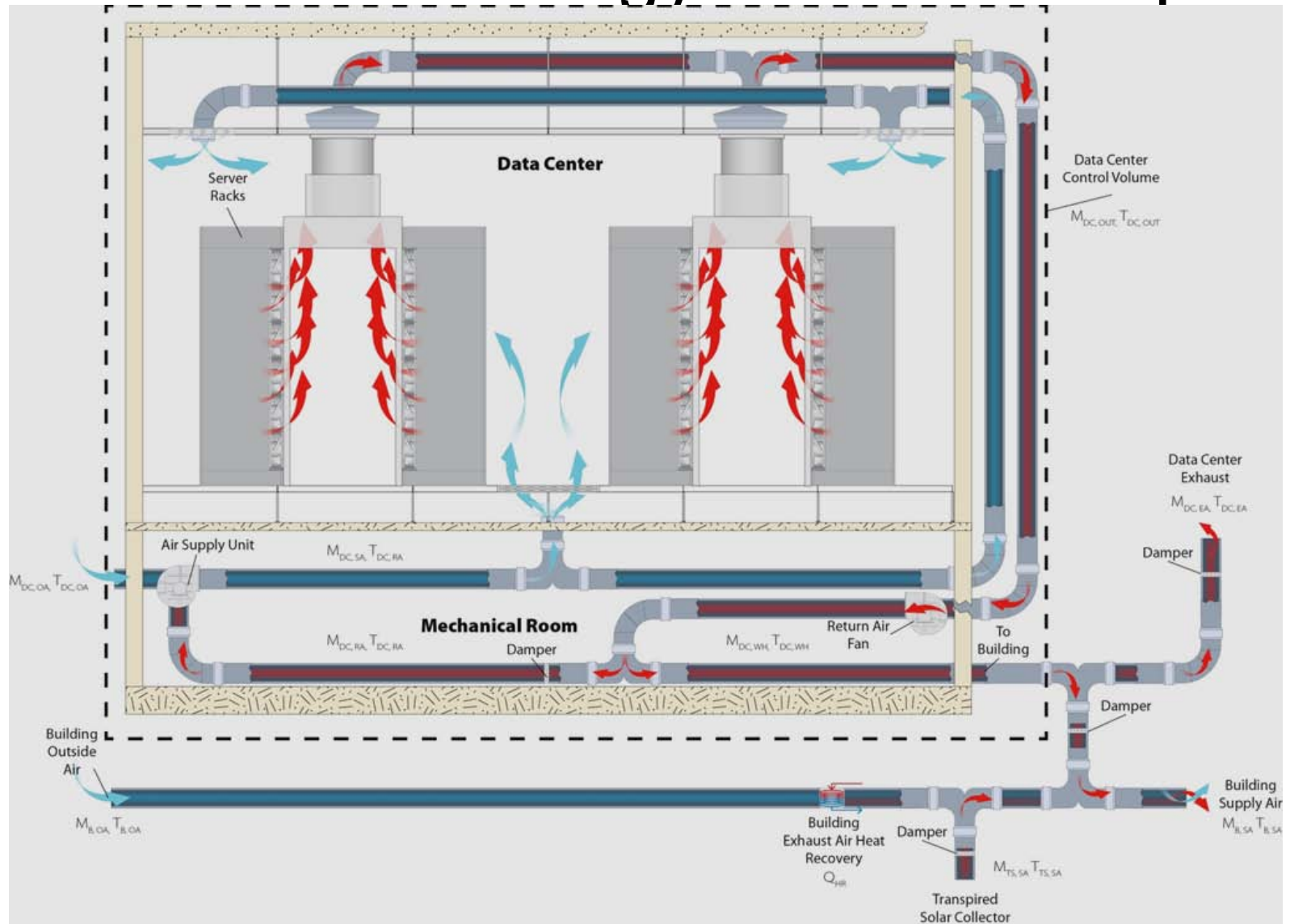
$$0 \leq ERE \leq \infty \quad ERE = \frac{\text{Cool} + \text{Pwr} + \text{Light} + IT - \text{Reused}}{IT}$$

heat recovery  
data center relief  
transpired collector  
labyrinth  
dual air intakes



**BASEMENT FLOOR PLAN**  
NREL RESEARCH SUPPORT FACILITY

# Data Center Energy Balance Graphic

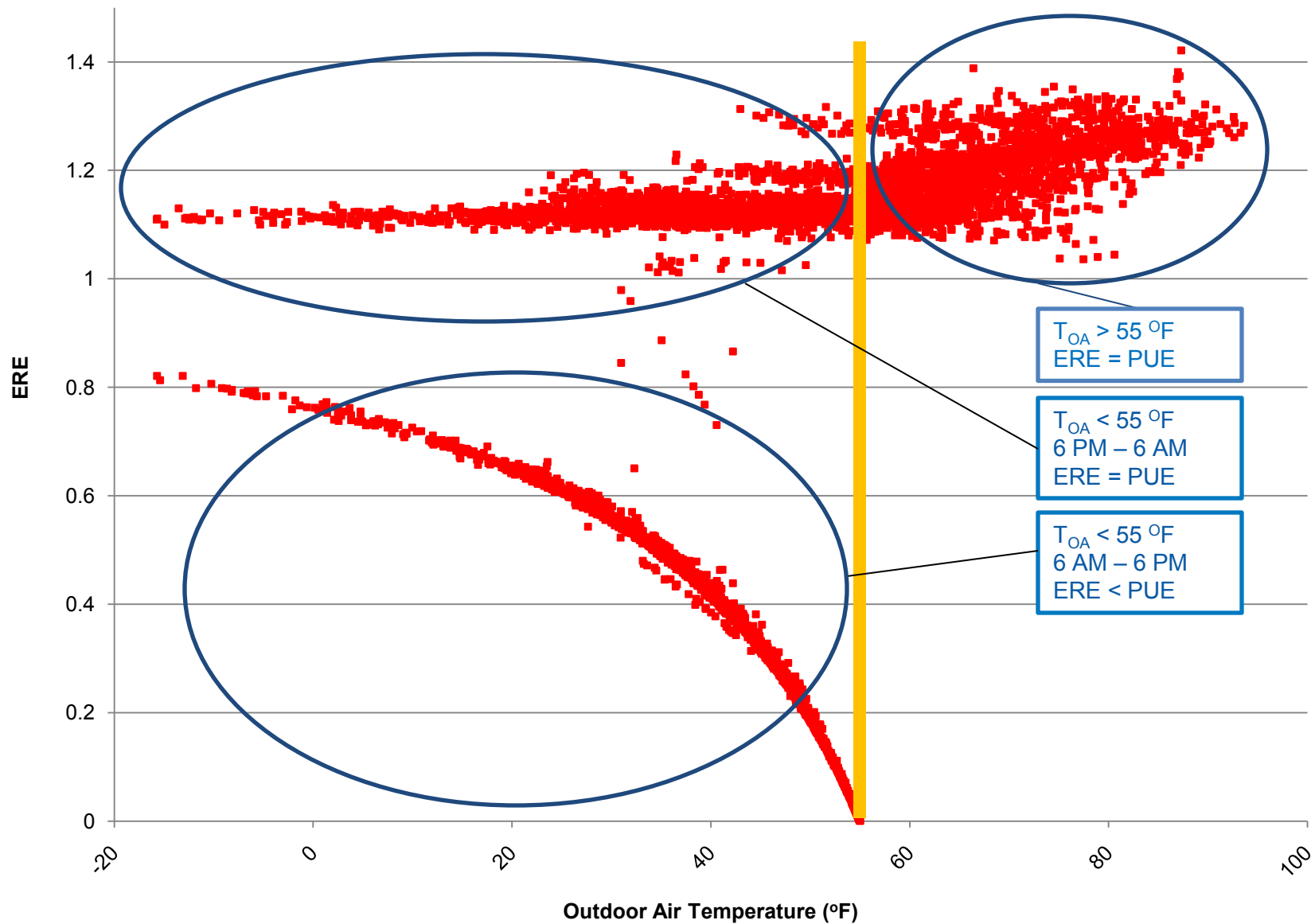


# Waste Heat Recovery Assumptions:

- No heat recovery:
  - When the outdoor air temperature is  $> 55$  °F
  - During unoccupied hours (6:00 PM to 6:00 AM)
- Constant humidity ratio
- Fraction of data center supply air that is outdoor air:
  - $OA\% = (T_{RA} - T_{SA}) / (T_{RA} - T_{OA})$
- Data center supply air temperature of 55 °F (fixed)
- Data center return air temperature of 80 °F (fixed)
- All data center waste heat is used to offset building heating loads when the above conditions are met.

# Time Series Graph: Oct '10 – July '11

## Data Center ERE vs Outdoor Air Temperature

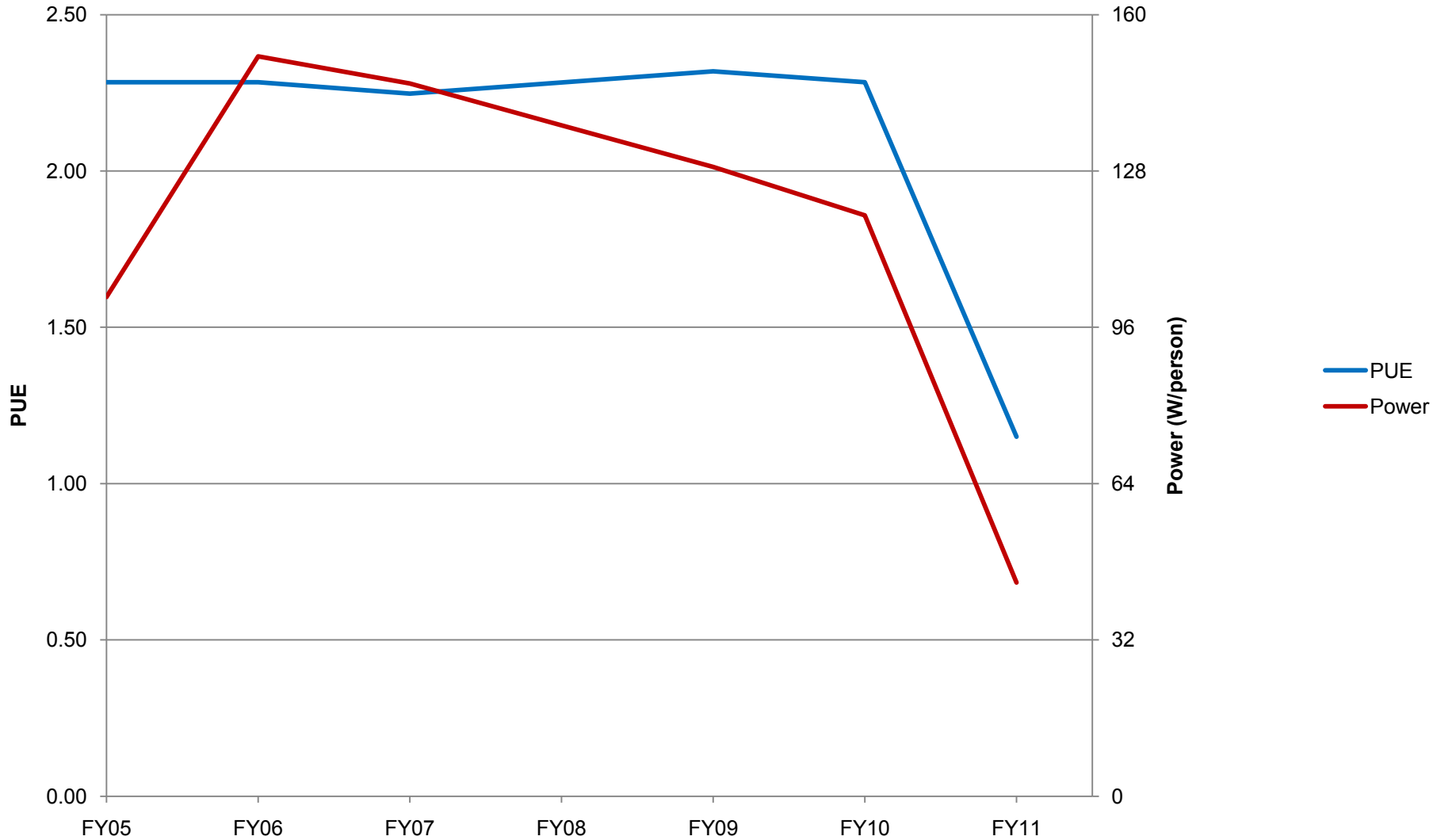


# Results

- Oct '10 – July '11:
- **Average ERE = 0.91 (calculated, not measured)**
- -Maybe lower if you assume that a fraction of the waste heat is used to offset building heating loads until the outdoor air temperature equals the building supply air temperature set point.
- **Average PUE = 1.18 (measured)**

# PUE and Power Per Person

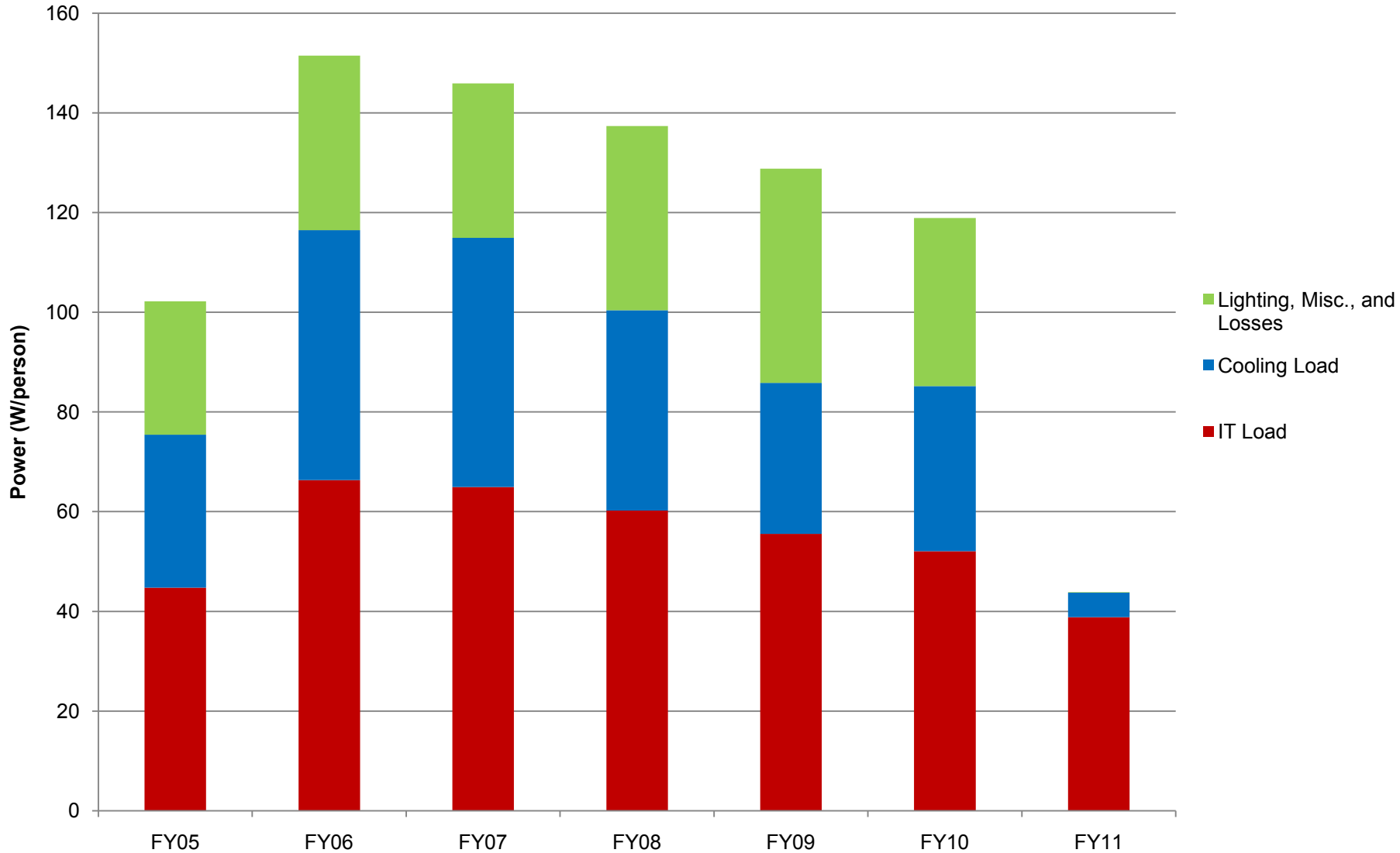
## Data Center PUE and Power Per Person





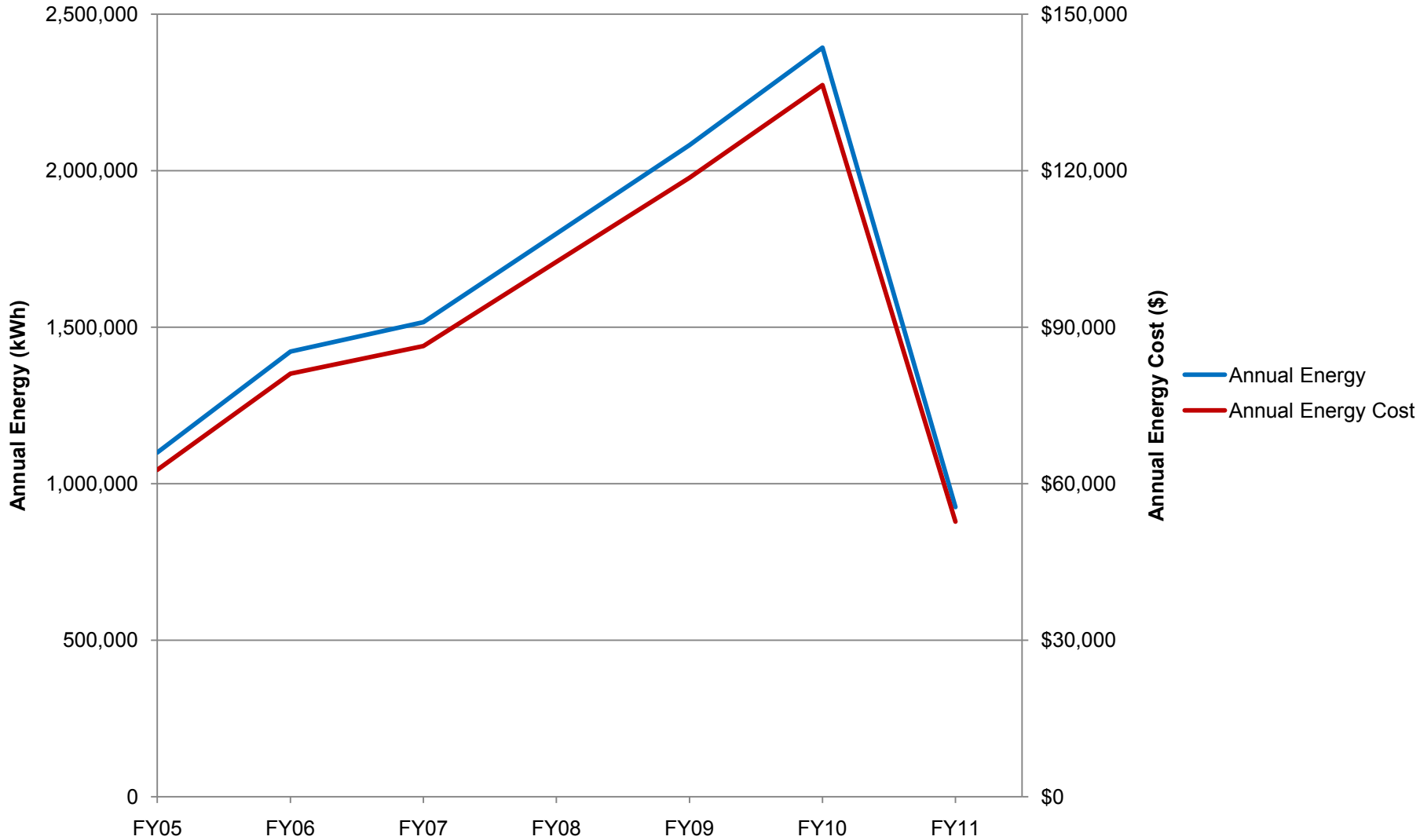
# Power Per Person

## Data Center Power Per Person



# Annual Energy and Energy Cost

## Data Center Annual Energy and Energy Cost



# Data Center Summary

- Include targets for Data Center PUE and ERE (climate dependant)
  - PUE <1.2
  - ERE < 0.9
- Design data center with hot isle – cold isle separation
- Use free cooling (economizer) and evaporative cooling when available
- Minimize fan energy
- Purchase the most energy-efficient equipment possible, Virtualization and consolidation
- Case-studies demonstrate that energy re-use is becoming more prevalent and the need for the ERE metric becomes a priority
- Low Energy DC with energy reuse cost effective

# Deployment Programs

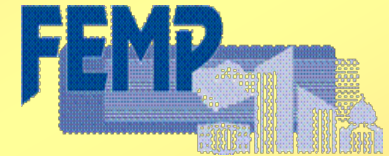
## Industrial Technologies Program

- Tool suite & metrics for baselining
- Training
- Qualified specialists
- Case studies
- Recognition of high energy savers
- R&D - technology development



## Federal Energy Management Program

- Workshops
- Federal case studies
- Federal policy guidance
- Information exchange & outreach
- Access to financing opportunities
- Technical assistance



## GSA

- Workshops
- Quick Start Efficiency Guide
- Technical Assistance



## EPA

- Metrics
- Server performance rating & ENERGY STAR label
- Data center benchmarking



## Industry

- Tools
- Metrics
- Training
- Best practice information
- Best-in-Class guidelines
- IT work productivity standard

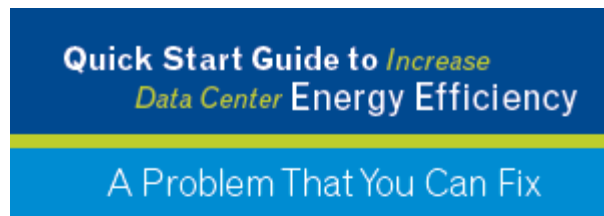


# DOE Federal Energy Management Program and Sustainability Project Office

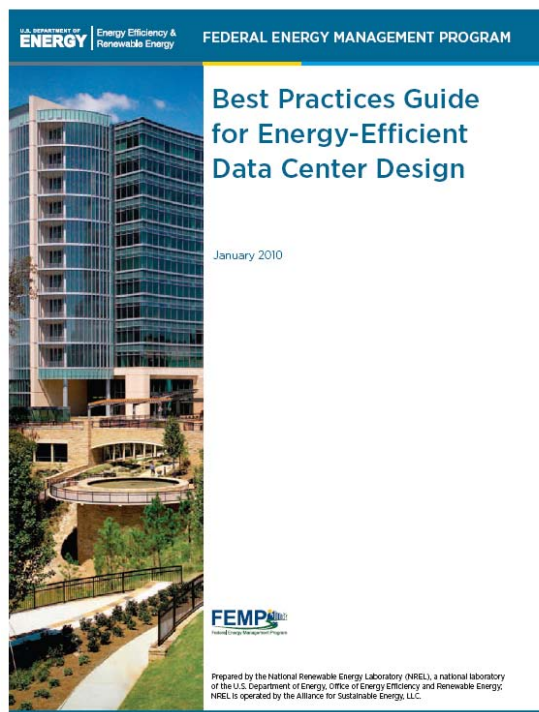
- Benchmarking and Assessments of Federal data centers
  - Potential drivers for consolidation
- Training
- Technical Assistance to Federal Agencies
  - Cost sharing with GSA, DOD, others
- Pilot adoption of technologies
- Federal procurement specifications
- Best practices guides, case studies, and other tools
- FEMP awards

# Data Center Resources

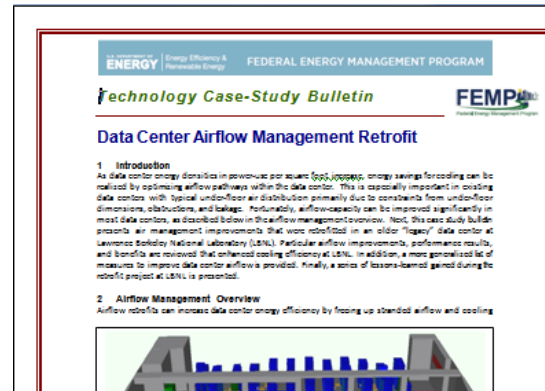
- Best Practices Guide
- Benchmarking Guide
- Data Center Programming Guide
- Technology Case Study Bulletins
- Procurement Specifications
- Report Templates
- Process Manuals
- Quick-Start Guide



Data Center energy efficiency is derived from addressing BOTH your hardware equipment AND your infrastructure. Less than half the power used by a typical data center powers its IT equipment. Where does the other half go? To support infrastructure including cooling systems, UPS inefficiencies, power distribution losses



Prepared by the National Renewable Energy Laboratory (NREL), a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. NREL is operated by the Alliance for Sustainable Energy, LLC.



**1 Introduction**  
As data center energy densities increase per square foot, energy savings for cooling can be realized by optimizing airflow pathways within the data center. This is especially important in cooling data centers with typical under-floor air distribution primarily due to constraints from under-floor dimensions, obstructions, and leakage. Fortunately, airflow capacity can be improved significantly in most data centers, as described below in the airflow management overview. Note, this case study bulletin presents air management improvements that were identified in an older "legacy" data center at Lawrence Berkeley National Laboratory (LBNL). Particular airflow improvements, performance results, and benefits are reviewed that enhanced cooling efficiency at LBNL. In addition, a more general list of measures to improve data center airflow is provided. Finally, a series of lessons-learned gained during the retrofit project at LBNL is presented.

**2 Airflow Management Overview**  
Airflow retrofits can increase data center energy efficiency by fixing or standardizing airflow and cooling



**1 Introduction**  
As data center energy densities increase in power-use per square foot, energy savings for cooling can be realized by incorporating liquid-cooling devices instead of increasing airflow volume. This is especially important in a data center with a typical under-floor cooling system. An airflow-capacity limit will eventually be reached that is constrained, in part, by under-floor dimensions and obstructions.

**2 Technology Overview**  
The rear door heat exchanger (RDHX) devices reviewed in this case study are referred to as passive devices because they have no moving parts, however, they do require cooling water flow. A passive RDHX contributes to optimizing energy efficiency in a data center facility in several ways. First, once the device is installed, it does not directly require infrastructure electrical energy to operate. Second, RDHX devices can use less chiller energy since they perform well at warmer (higher) chilled water set-points. Third, depending on climate and piping arrangements, RDHX devices can eliminate chiller energy because they can use treated water from a plate-and-frame heat exchanger connected to a cooling tower. These inherent features of a RDHX help reduce energy use while minimizing maintenance costs.

**2.1 Basic operation**  
The RDHX device, which resembles an automobile radiator, is placed in the airflow outlet of a server rack.

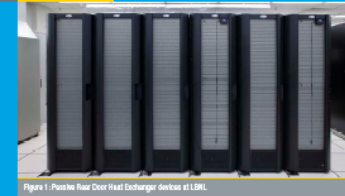


Figure 1: Passive Rear Door Heat Exchanger device at LBNL.

During operation, hot server-rack airflow is forced through the RDHX device by the server fan. Heat is exchanged from the hot air to circulating water from a chiller or cooling tower. Thus, server-rack outlet air temperature is reduced before it is discharged into the data center.

**2.2 Technology Benefits**  
RDHX cooling devices can save energy and increase operational reliability in data centers because of straightforward installation, simple operation, and low maintenance. These features, combined with compactness, indirect evaporative cooling, make RDHX a viable technology in both new and retrofit data center designs. It may also help eliminate the complexity and cost of under-floor air distribution.

**Reduce Maintenance**  
Because passive RDHX devices have no moving parts, they require less maintenance compared to computer room air conditioning (CRAC) units. RDHX devices will require occasional cleaning of dust and lint from the air-side of the coils. RDHX performance also depends on proper water-side maintenance.

**Reduce or Eliminate Chiller Operation**  
RDHX devices present an opportunity to save energy by either reducing or

# FEMP/GSA Partnership

Increase Your Data Center Energy Efficiency • Increase Your Data Center Energy Efficiency • Increase Your Data Center Energy Efficiency • Increase Your Data Center Energy Efficiency • Increase Your Data Center Energy Efficiency • Increase Your Data Center Energy Efficiency

## Quick Start Guide To Increase Your Data Center Energy Efficiency

### 5 Five More Best Practices

#### Optimize the Central Plant

Typically, a central cooling plant and air handlers are more efficient than distributed air conditioning units. Begin with an efficient water-cooled variable speed chiller, add high-efficiency air handlers, low-pressure drop components, and finish with an integrated control system that minimizes unnecessary dehumidification and simultaneous heating and cooling.

Use temperature resets to allow use of medium-temperature water "chilled" (55-degrees Fahrenheit or higher). Warm water chiller improves chiller plant efficiency and eliminates the need for the chiller during many hours of operation (lower cooling only).

#### Free Cooling

Can you design your building for free cooling? Can you retrofit outside air supply? Can you retrofit a water side economizer (use cooling tower pre-cool return "chilled" water)? It is all about humidity and temperature.

#### Right Sizing

When the ultimate load is uncertain, data center cooling systems are often oversized and operate at inefficient part-loads. Therefore, it makes sense to pre-install fixed elements such as ducts and pipes, but design for modular growth of the mechanical equipment. Include variable speed fans, pumps and compressors. Right size all your plant equipment—overbuilding in advance of actual needs makes many air systems operate inefficiently.

#### Use Liquid Cooling of Racks and Computers

Since water is 2000 times more effective than air on a volume basis, it cools servers and appliances more efficiently than air conditioning. Today, you can purchase liquid-cooled racks. Manufacturers are prototyping liquid-cooled computers as well.

#### People are Key

Facilities and IT staff bring different perspectives to create better solutions when it comes to data center energy efficiency. Ask your counterpart to lunch so you can begin to learn about their challenges and explain your own.

This Guide is funded by U.S. General Services Administration and U.S. Department of Energy's Federal Energy Management Program



### 6 What Can You Really Achieve?

#### Save energy now.

#### Improve Design and Operations Processes

- Benchmark existing facilities
- Document design intent
- Introduce energy optimization early in the design process
- Use life-cycle total cost of ownership analysis
- Re-commission as a regular part of maintenance
- Encourage IT and facilities people to work together

#### More Information

You can learn more about these topics at the following URL:

- Air management
- Right-sizing
- Central plant optimization
- Efficient air handling
- Free-cooling
- Humidity control
- Server efficiency (see Energy Star®)
- Liquid cooling
- Improving power chain
- UPSs and equipment power supplies
- On-site generation
- Designing, measuring & optimizing processes

#### Useful Websites:

Sign up here to stay up to date on the DCE website:  
[www.ere.energy.gov/datacenters](http://www.ere.energy.gov/datacenters)

#### Energy Star® Program:

[www.energystar.gov/index.cfm?c=prod\\_development.server\\_efficiency](http://www.energystar.gov/index.cfm?c=prod_development.server_efficiency)

#### Lawrence Berkeley National Laboratory (LBNL):

<http://hightech.lbl.gov/datacenters.html>

#### LBNL Best Practices Guidelines (cooling, power, IT systems):

<http://hightech.lbl.gov/datacenters-bpp.html>

#### ASHRAE Data Center technical guidebooks:

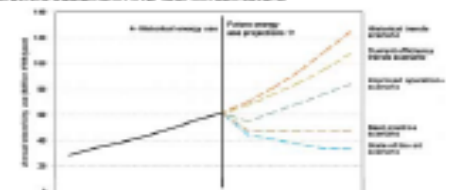
<http://itc@ashrae.org>

### 1 We have a problem that we can fix.

- The energy used by a single rack of the emerging generation of servers (10kW plus air-conditioning) each year (and associated air-conditioning) is equivalent to the energy required to drive an average car (20-miles per gallon) coast-to-coast about 100 times. (Source: Evan Mills, Lawrence Berkeley Lab, 2006).
- Electric bill could exceed the cost of IT equipment over its useful life. 20-40% savings are typically possible, aggressive strategies can yield better than 50% savings.

We make choices every day that affect our carbon footprint. As the chart below shows, we are choosing how much effort we will exert in order to decrease our data center carbon footprint.

Data Center energy efficiency is derived from addressing BOTH your hardware equipment AND your infrastructure.



Source: The Green Grid Data Center Energy Efficiency Metrics (DCEM) 2.0

#### High Level Facility Metrics

#### PUE (Power Usage Effectiveness) and DCIE (Data Center Infrastructure Efficiency)



Both PUE (Power Usage Effectiveness) and DCIE (Data Center Infrastructure Efficiency) are accepted measures of overall data center efficiency.

PUE = Total Facility Power / IT Equipment Power  
DCIE = IT Equipment Power / Building Load Demand  
Source: The Green Grid Data Center Energy Efficiency Metrics 2.0

# DOE DC Pro Tool Suite

## High-Level On-Line Profiling and Tracking Tool

- Overall efficiency (Power Usage Effectiveness [PUE])
- End-use breakout
- Potential areas for energy efficiency improvement
- Overall energy use reduction potential

## In-Depth Assessment Tools → Savings

### Air Management

- Hot/cold separation
- Environmental conditions
- RCI and RTI

### Electrical Systems

- UPS
- PDU
- Transformers
- Lighting
- Standby gen.

### IT-Equipment

- Servers
- Storage & networking
- Software

### Cooling

- Air handlers/conditioners
- Chillers, pumps, fans
- Free cooling



# Resources



[http://www1.eere.energy.gov/femp/program/data\\_center.html](http://www1.eere.energy.gov/femp/program/data_center.html)



<http://hightech.lbl.gov/datacenters.html>



[http://www.energystar.gov/index.cfm?c=prod\\_development.server\\_efficiency](http://www.energystar.gov/index.cfm?c=prod_development.server_efficiency)



<http://www1.eere.energy.gov/industry/datacenters/>





**RSF II**  
**21 kBtu/ft<sup>2</sup>**  
**\$246/ft<sup>2</sup> construction cost**

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