数据中心能效最佳实践
Best Practices for Data Center Energy Efficiency

Data Center Dynamics, Chengdu

June 25, 2013

报告人 Presented by:

夏明德，注册工程师
美国劳伦斯伯克利国家实验室
Dale Sartor, P.E.
Lawrence Berkeley National Laboratory

(Version: 6/9/13)

下载报告
Download Presentation

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

本次报告的内容可在以下网站上下载：

http://datacenterworkshop.lbl.gov/

This Presentation is Available for download at:

http://datacenterworkshop.lbl.gov/

报告提纲 AGENDA

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 介绍课程内容和课程讲师
- 数据中心绩效指标和对标
- IT设备和软件效率
- 利用IT现IT节能（监测和结果展示）
- 数据中心运行环境条件
- 数据中心气流管理
- 冷气系统
- 电气系统
- 参考资料和本研讨会总结

- Introductions to course and instructors
- Performance metrics and benchmarking
- IT equipment and software efficiency
- Use IT to save IT (monitoring and dashboards)
- Data center environmental conditions
- Airflow management
- Cooling systems
- Electrical systems
- Resources and Workshop Summary

传统方法
Conventional Approach

- 数据中心需要冷气并控制在窄小的湿度区间内

  Data centers need to be cool and controlled to tight humidity ranges
- 数据中心需要高架地板，从而通过地板输送冷空气

  Data centers need raised floors for cold air distribution
- 数据中心需要冗复的建筑基础设施

  Data centers require highly redundant building infrastructure

需要综合的方法

Need Holistic Approach

- IT和设施的伙伴关系
  IT and Facilities Partnership

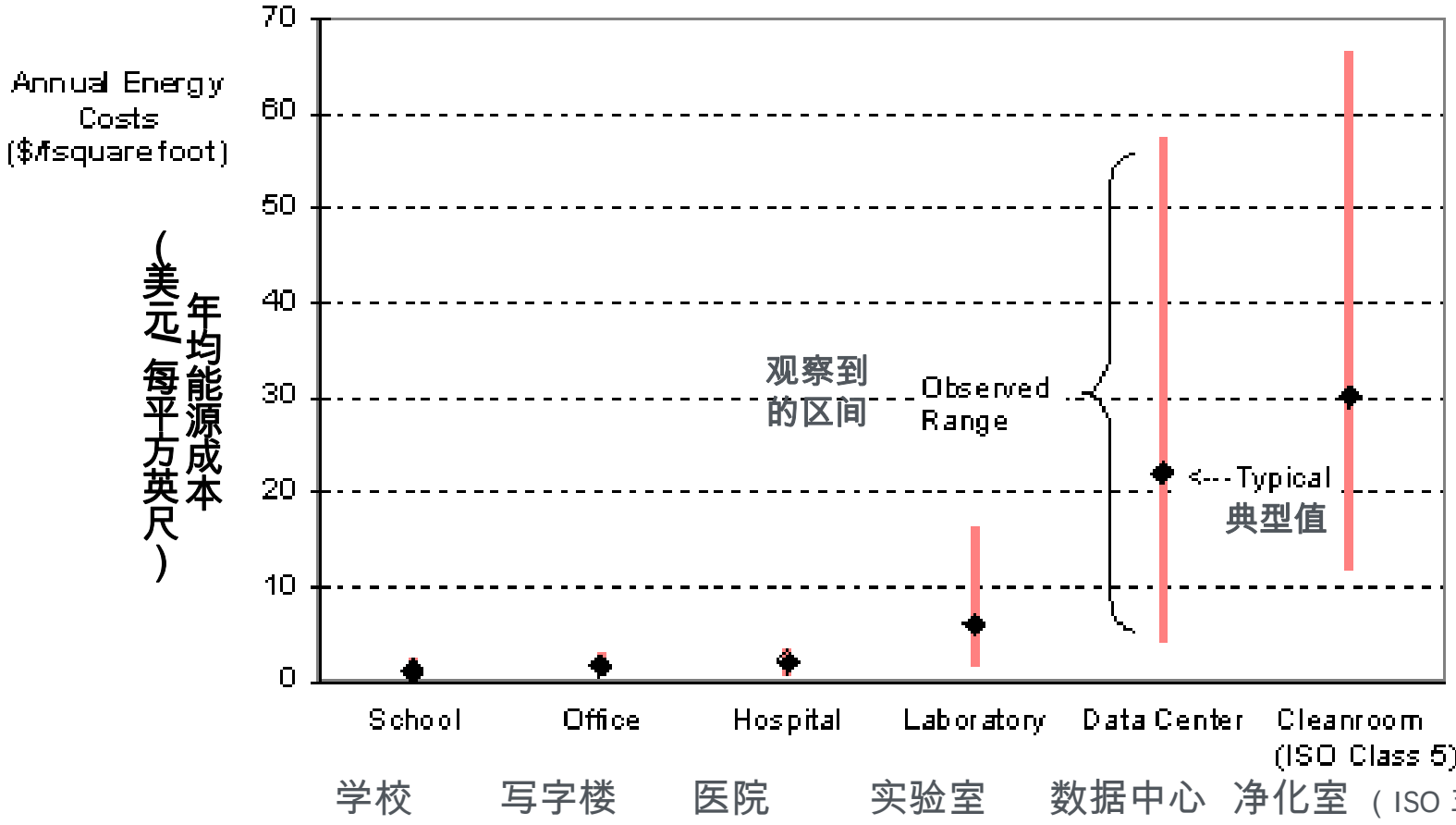
介绍

Introduction

高科技建筑往往消耗大量能源
High Tech Buildings are Energy Hogs

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

能源成本对比——高科技建筑与普通建筑的对比
Comparative Energy Costs
High-Tech Facilities *vs.* Standard Buildings

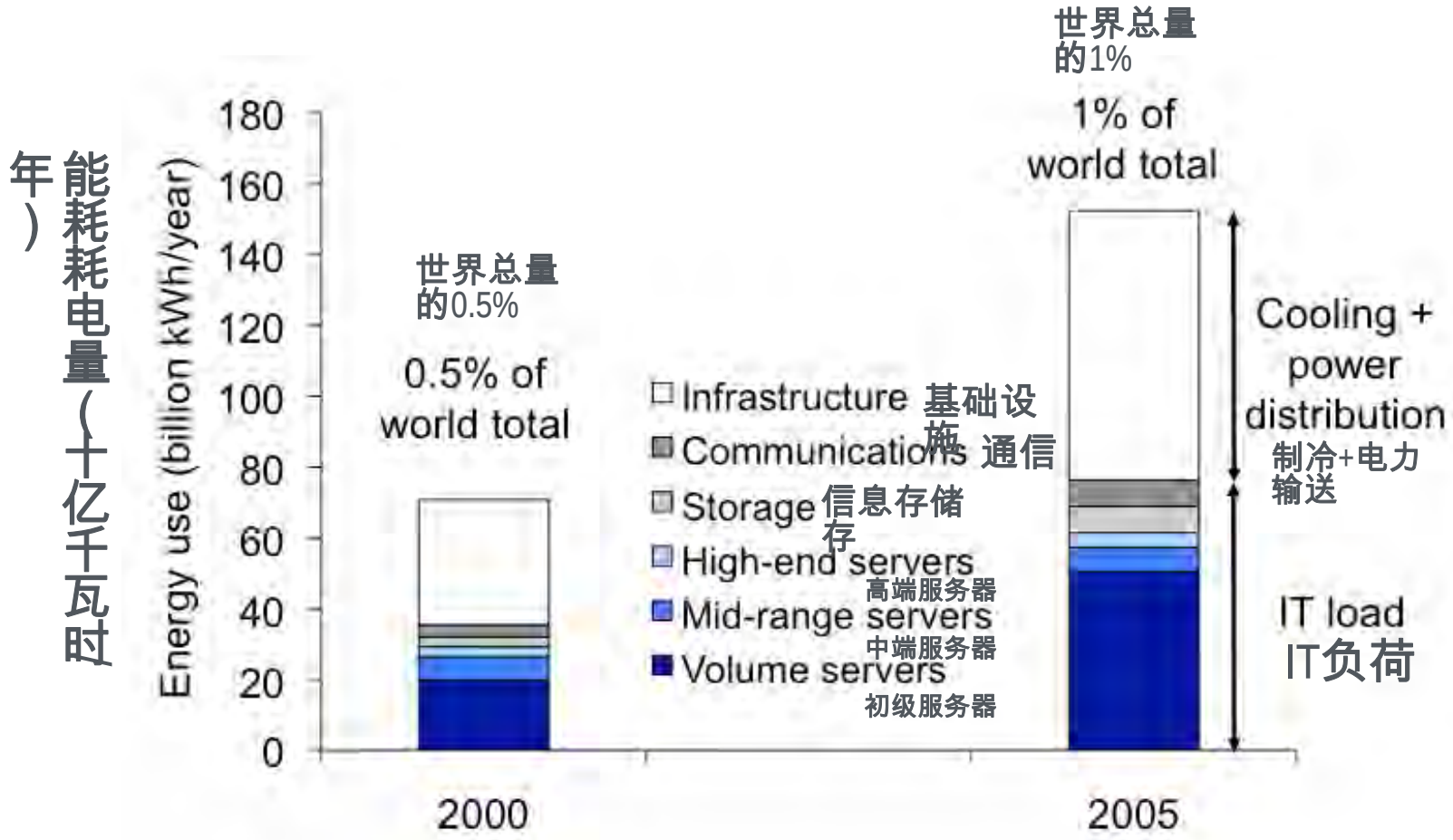


数据中心是制造信息的工厂
Data Centers are INFORMATION FACTORIES

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 数据中心是能源密集型设施
  Data centers are energy intensive facilities
  - 现在的服务器机柜设计容量超过25千瓦
    Server racks now designed for more than 25+ kW
  - 对数据存储容量的需要大幅增长
    Surging demand for data storage
  - 典型的数据中心：约100万瓦，甚至也可超过2000万瓦
    Typical facility ~ 1MW, can be > 20 MW
  - 占美国2006年电力消耗的1.5%
    1.5% of US Electricity consumption in 2006
  - 预计在未来5年内番一倍
    Projected to double in next 5 years
- 新建的数据中心大量涌现
  Significant data center building boom
  - 已有的数据中心存在供电和制冷的限制
    Power and cooling constraints in existing facilities
  - 供电系统的限制
    Utility distribution constraints

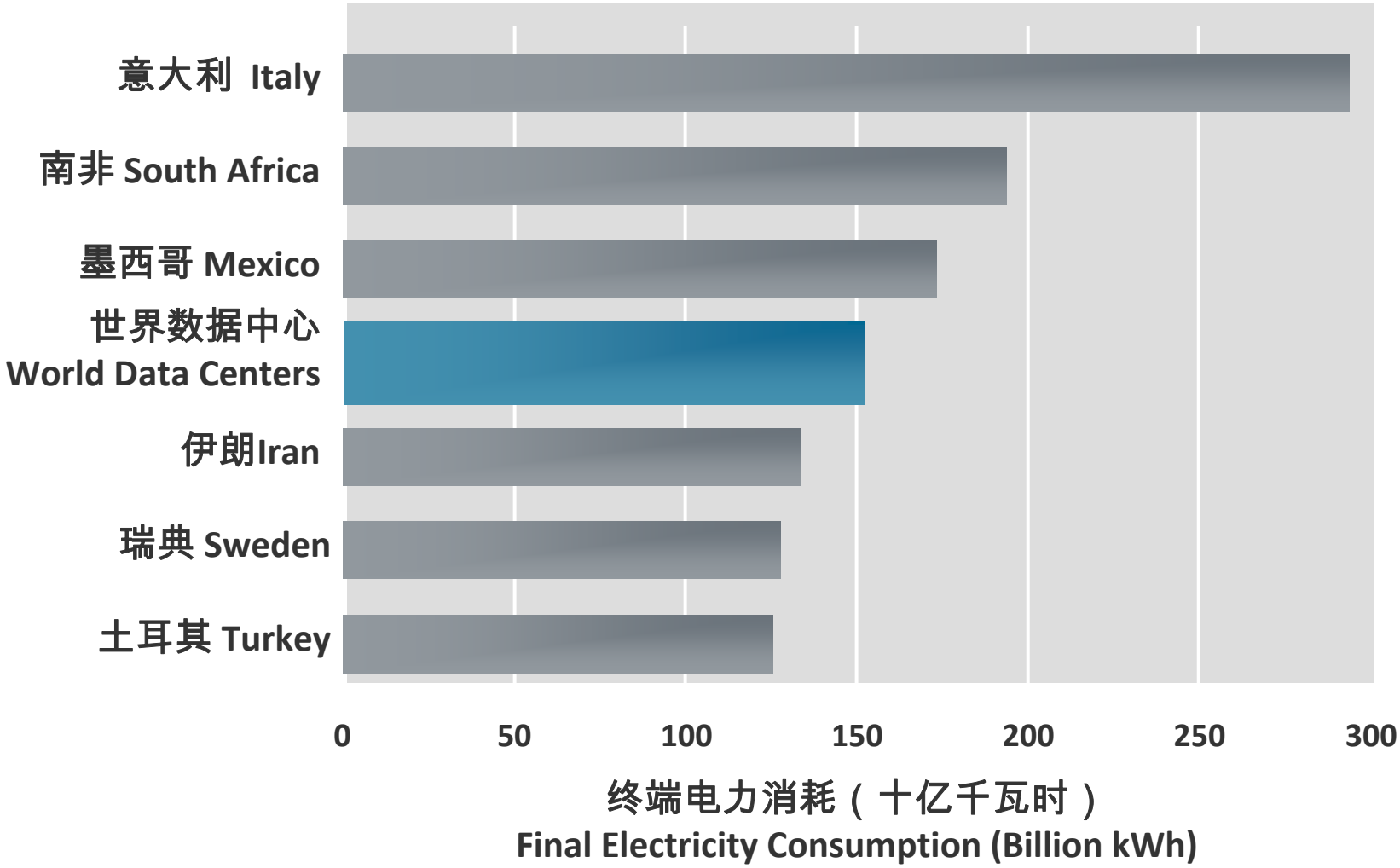
世界数据中心的电耗
World Data Center Electricity Use



Source: Koomey 2008

1520亿度电是多少？
How much is 152B kWh?

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



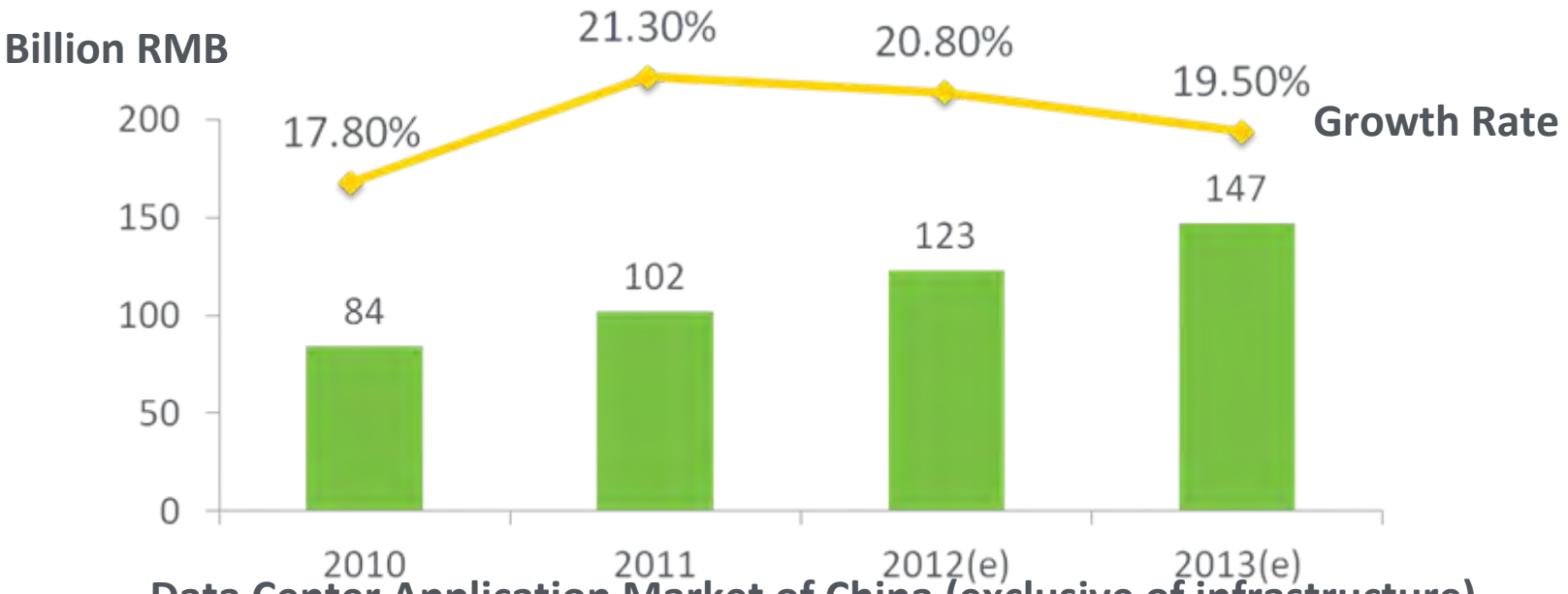
2005年数据来源：国际能源署，世界能源平衡表（2007年版）

Source for country data in 2005: International Energy Agency, *World Energy Balances* (2007 edition)

Development of Data Center in China
中国数据中心发展

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- China has constructed over 500,000 data centers. The number will rise up to 540,777 at the end of 2012. The market for data center application in 2012 will be 123 billion RMB with CAGR of 18.6%.
- 中国目前已建成了超过50万个数据中心，预计到2012年年底，将建成54万个数据中心。2011年其应用市场规模达1020亿元，年复合增涨率为18.6%。



Data Center Application Market of China (exclusive of infrastructure)
数据中心应用市场规模（不包括基础设施）

Development of Data Center in China
中国数据中心发展

As cloud computing becomes a key project in 12th FYP, to support the project, major cities such as Beijing, Shanghai, Tianjin, Shenzhen Chongqing, are going to establish data centers containing up to one million servers each.

“云计算”是中国“十二五”规划的重要工程。为提供必要支持，各主要城市如北京、上海、天津、深圳、重庆均计划建设容纳几十万至上百万服务器的数据中心。

Development of Data Center in China
中国数据中心发展

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

The annual combined electricity consumption of China's data centers accounts for over 2% of China's total electricity use, or 10% of the electricity consumption of China's building sector, almost the same as the electricity produced by the entire Three Gorge Dam.

中国数据中心消耗的电量占全社会总电力消耗的2%，或全国建筑总能耗的10%，相当于三峡大坝全年的产能。

The PUE of typical China's data center is 2.2~3.0, which is much higher than global average, and the average utilization ratio is only 20%~30%.

中国典型数据中心的PUE仅为2.2~3.0，远高于世界平均水平，并且利用率仅有20%~30%。

运行数据中心成本的增加
The Rising Cost of Ownership

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 从2000年到2006年，计算性能提高了25倍，但是能效却只提高了8倍

  From 2000 – 2006, computing performance increased 25x but energy efficiency only 8x

  - 每购买1000美元的服务器所消耗的电量增加了4倍

    Amount of power consumed per $1,000 of servers purchased has increased 4x

- 目前，电力和数据中心辅助设施的成本已经超过了购买IT设备的费用

  Cost of electricity and supporting infrastructure now surpassing capital cost of IT equipment

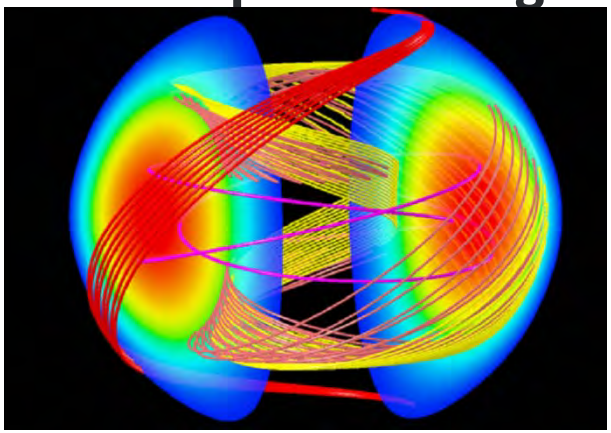
- 反向激励——IT 成本与数据中心设施成本相互分离

  Perverse incentives -- IT and facilities costs separate

来源：The Uptime Institute, 2007

Source: The Uptime Institute, 2007

LBNL 运行大型系统，同时还有以前的系统
LBNL operates large systems along with legacy systems



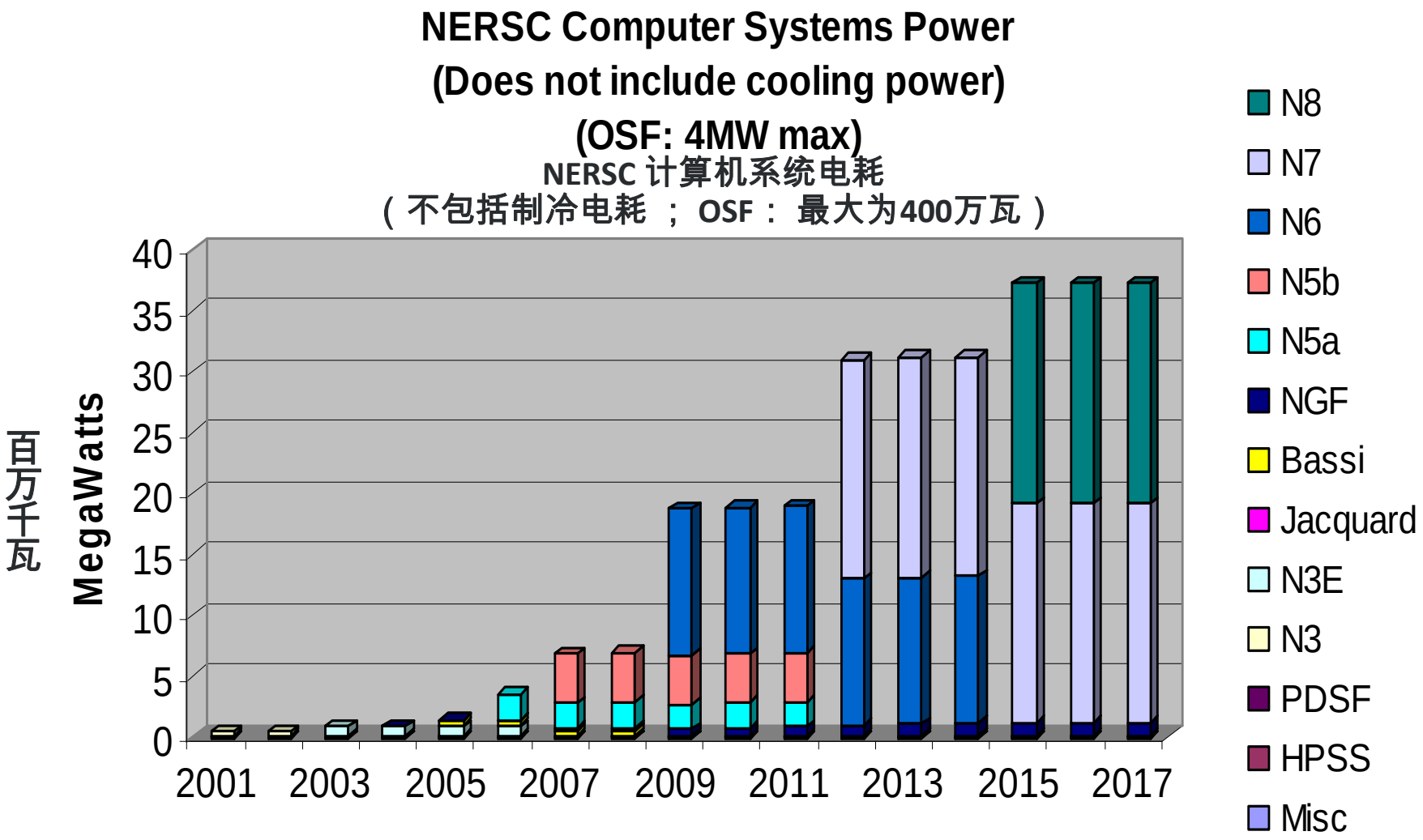
我们也研究节能机会，并开展多种推广和应用的项目
We also research energy efficiency opportunity and work on various deployment programs

LBNL也感受到了数据中心带来的压力！
LBNL Feels the Pain!

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

LBNL 超级计算机系统的电耗
LBNL Super Computer Systems Power

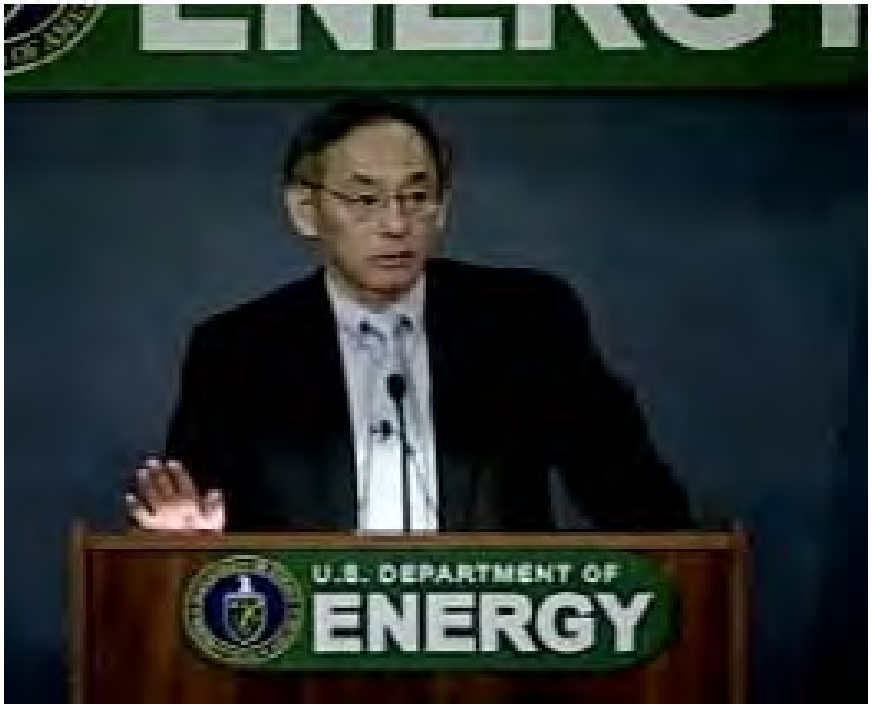
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



首先，我们的领导人的看法
First, a Few Words from our Leader

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- “我们现在显然处于一团混乱中。”
  “We’re certainly in a mess right now.”
- “这样的环境……是我加入美国能源部的原因。”
  “The environment... is the reason I joined the Dept of Energy.”
- “我们不能在这方面失败。”
  “We simply cannot fail.”



来源：能源部长朱棣文在美国能源部对能源部工作人员的讲话
2009年1月22日

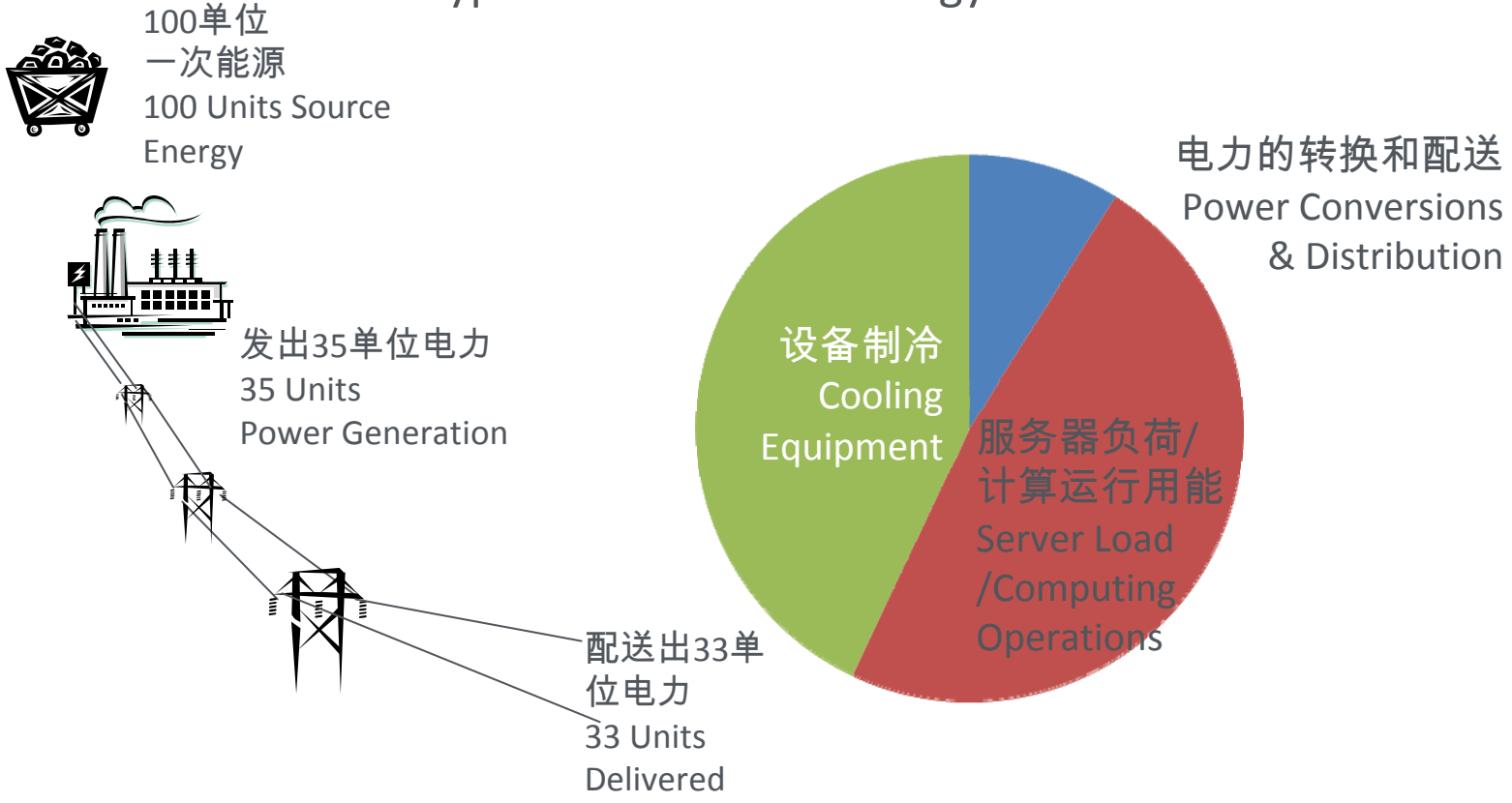
Source: Secretary Chu’s address to DOE staff 1/22/09

数据中心的能效= 15%（或更少）
Data Center Energy Efficiency = 15% (or less)

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

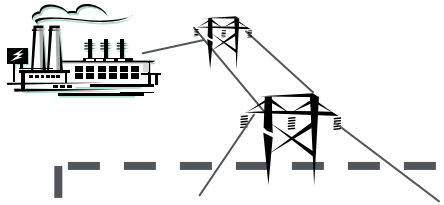
（能效=用于计算之能耗/一次能源消耗量）
(Energy Efficiency = Useful computation / Total Source Energy)

典型的数据中心终端能源消耗
Typical Data Center Energy End Use



提高能效的机会
Energy Efficiency Opportunities

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



- 服务器创新
  Server innovation
- 虚拟化计算 Virtualization
- 高能效电力供给 High efficiency power supplies
- 负荷管理
  Load management

- 气流管理 Better air management
- 直接液冷 Move to liquid cooling
- 制冷机组优化
  Optimized chilled-water plants
- 使用自然制冷 Use of free cooling
- 热回收 Heat recovery

电力转换和配送
Power Conversion & Distribution

服务器负荷和计算运行用能
Server Load/ Computing Operations

制冷设备
Cooling Equipment

- 高压配电 High voltage distribution
- 高效UPS（不间断电源）系统
  High efficiency UPS systems
- 高效冗余策略
  Efficient redundancy strategies
- 使用直流电 Use of DC power

可替代燃料发电
Alternative Power Generation

- 自发电，包括燃料电池和可再生资源
  On-site generation Including fuel cells and renewable sources
- 热电联产的应用（利用废热制冷）
  CHP applications (Waste heat for cooling)

数据中心提高能效的好处
Potential Benefits of Data Center Energy Efficiency

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 典型节能量：20%-40%

  20-40% savings typical

- 更积极的策略和措施可以实现超过50%的节能量

  Aggressive strategies can yield 50+% savings

- 延长基础设施的使用寿命和容量

  Extend life and capacity of infrastructures

Questions? 问题？

报告提纲 AGENDA

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 介绍课程内容和课程讲师
- 绩效指标和对标
- IT设备和软件效率
- 利用It节约IT（监测和结果展示）
- 数据中心环境条件
- 气流管理
- 制冷系统
- 电气系统
- 参考资料和研讨会总结

- Introductions to course and instructors
- **Performance metrics and benchmarking**
- **IT equipment and software efficiency**
- **Use IT to save IT (monitoring and dashboards)**
- **Data center environmental conditions**
- **Airflow management**
- **Cooling systems**
- **Electrical systems**
- **Resources and Workshop Summary**

绩效指标和对标

Performance metrics and benchmarking

通过对标改善能效
Benchmarking for Energy Performance Improvement:

- 能效对标可以让公司与同行进行对比，从而帮助他们找到可以提高能效的最佳实践

  Energy benchmarking can allow comparison to peers and help identify best practices

- LBNL对超过30家数据中心进行了研究：

  LBNL conducted studies of over 30 data centers:

  - 发现各数据中心的能效表现有很大的差距

    Found wide variation in performance
  - 寻找数据中心节能的最佳实践

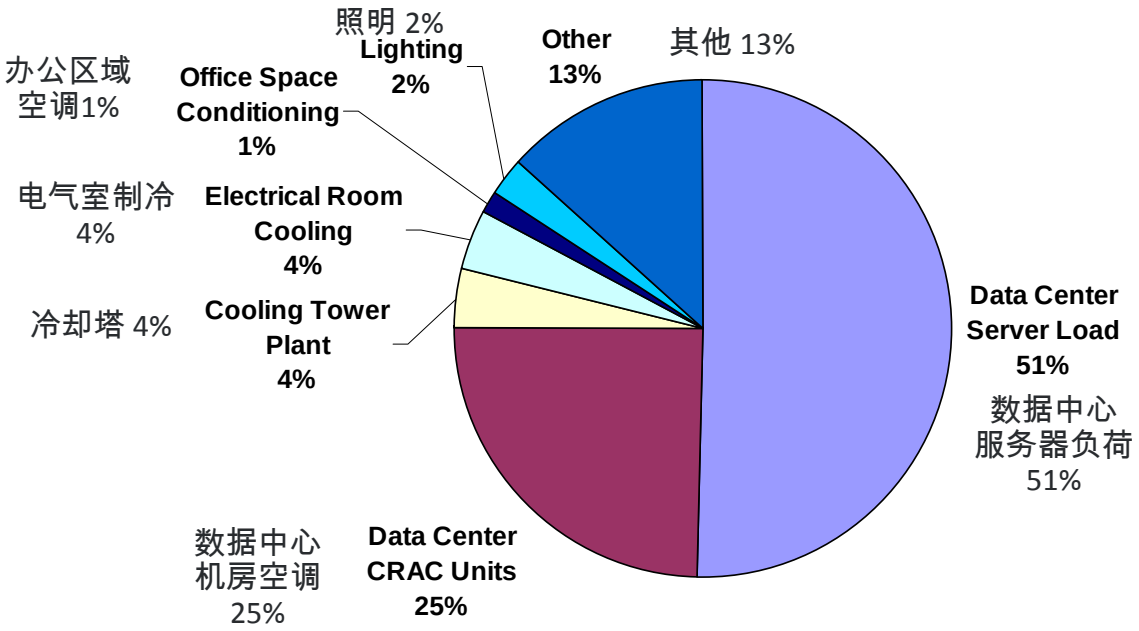
    Identified best practices

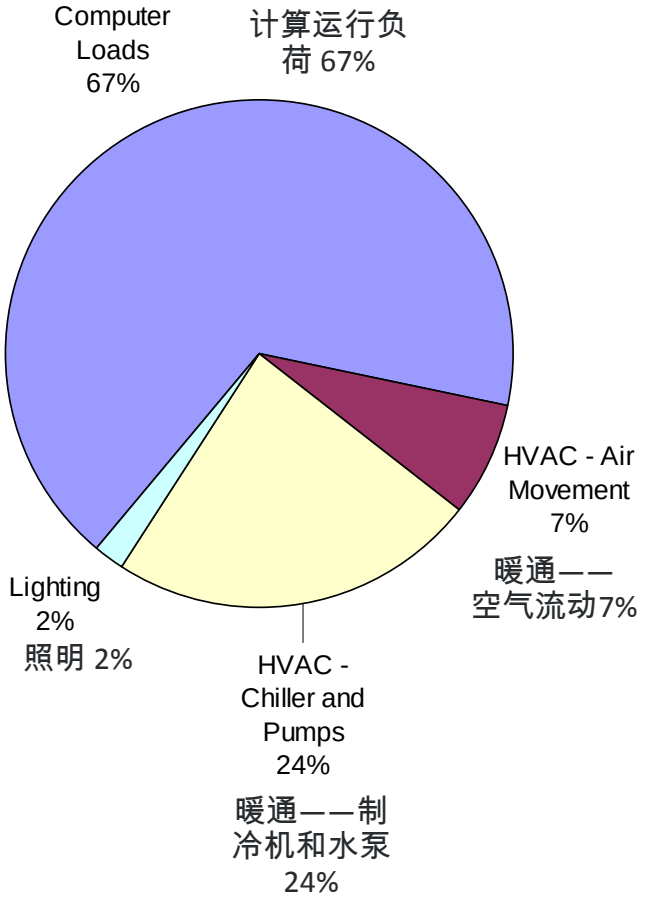
数据中心的用能情况各有不同
Your Mileage Will Vary

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

用于进行计算的能耗比例在不同的数据中心中有很大的区别

The relative percentages of the energy actually doing computing varied considerably.



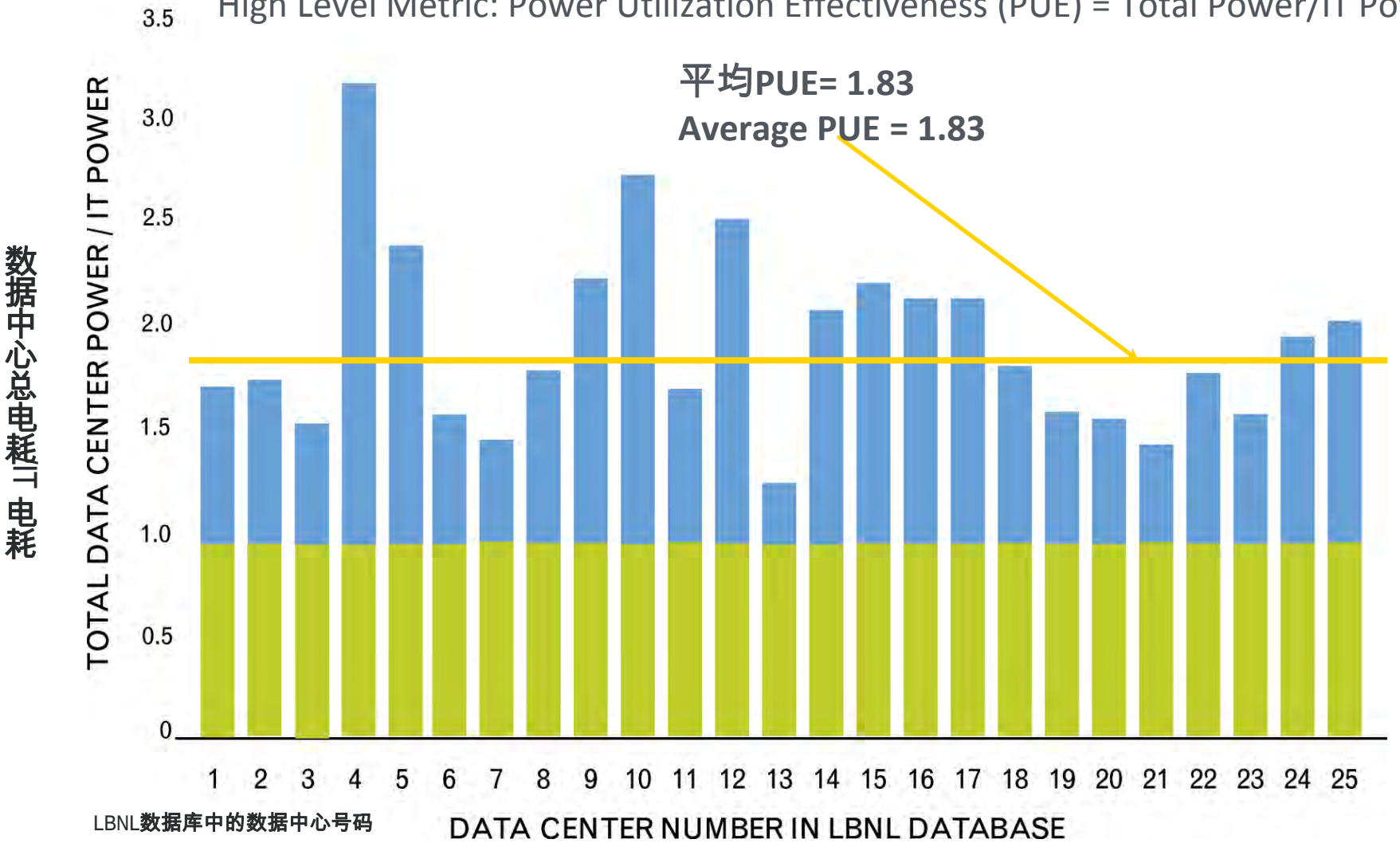


LBNL获得的对标结果
Benchmarks obtained by LBNL

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

综合指标：电能利用效率（PUE）= 总电耗/IT 电耗

High Level Metric: Power Utilization Effectiveness (PUE) = Total Power/IT Power



Questions? 问题？

报告提纲 AGENDA

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

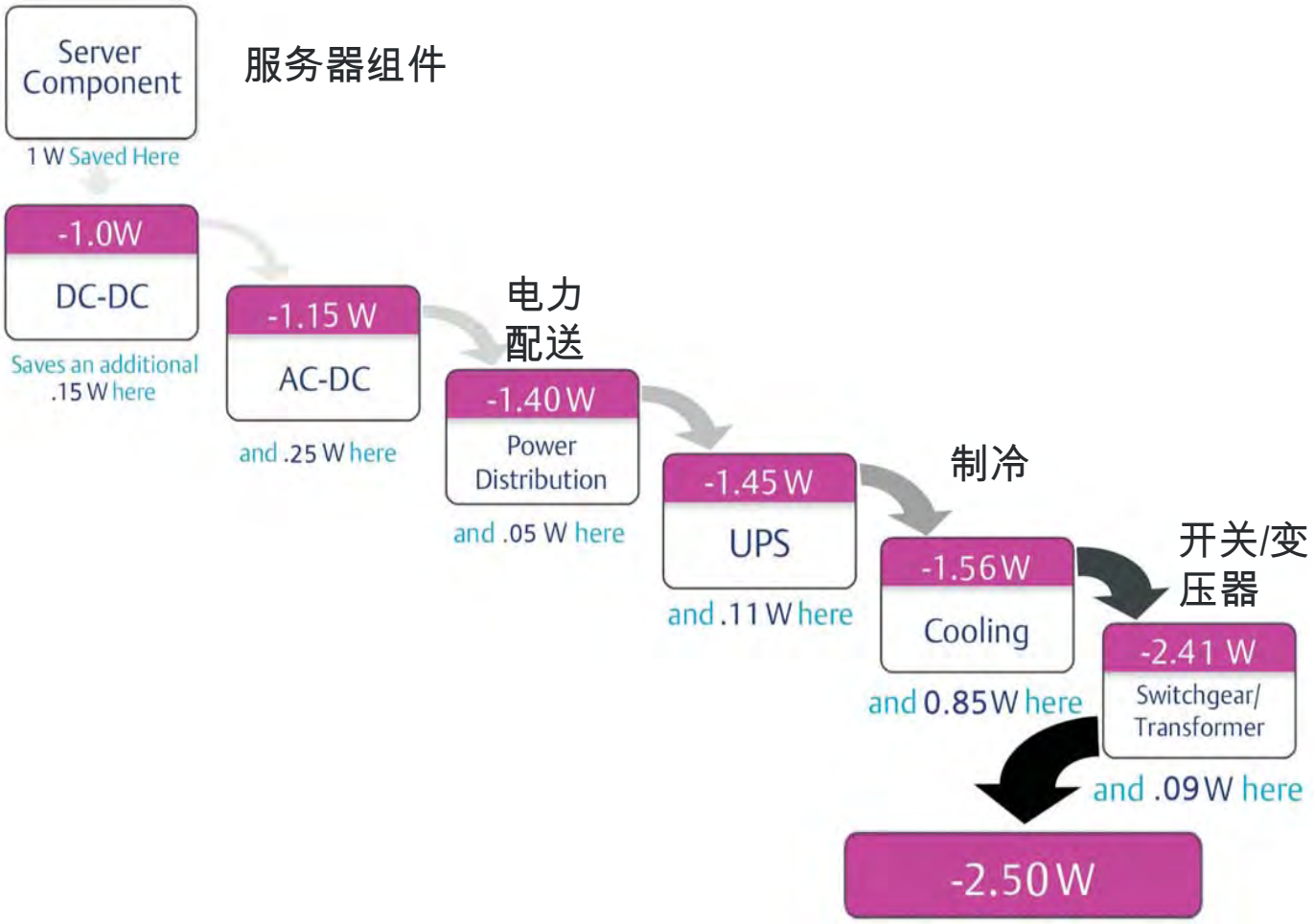
- 介绍课程内容和课程讲师
- 数据中心绩效指标和对标
- IT设备和软件效率
- 利用IT节约IT（监测和结果展示）
- 数据中心环境条件
- 气流管理
- 制冷系统
- 电气系统
- 参考资料和研讨会总结

- Introductions to course and instructors
- Performance metrics and benchmarking
- **IT equipment and software efficiency**
- **Use IT to save IT (monitoring and dashboards)**
- **Data center environmental conditions**
- **Airflow management**
- **Cooling systems**
- **Electrical systems**
- **Resources and Workshop Summary**

IT设备和软件效率

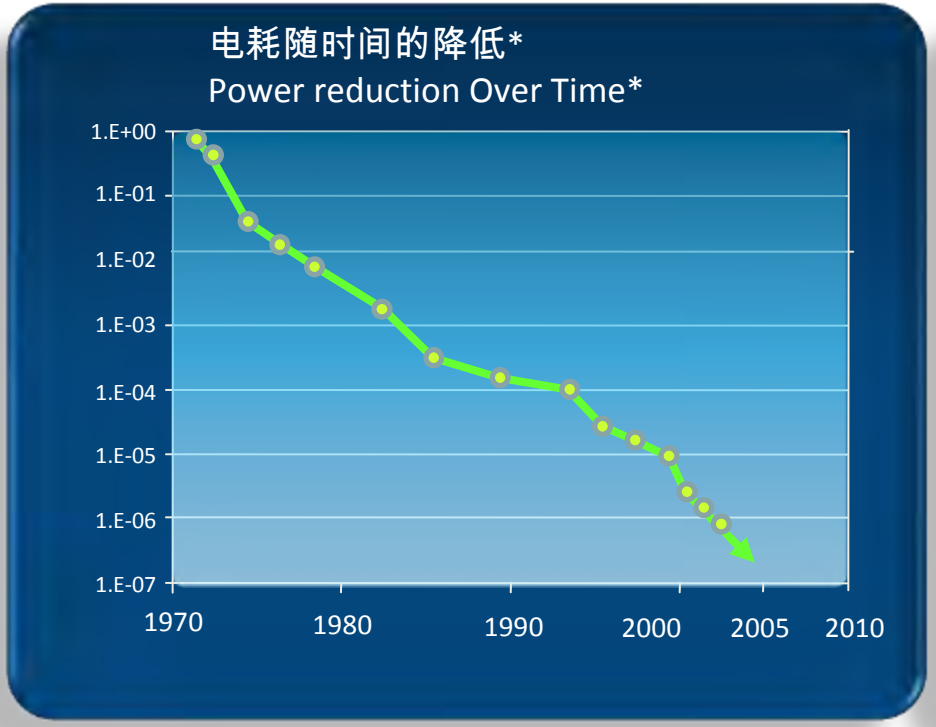
IT Equipment and Software Efficiency

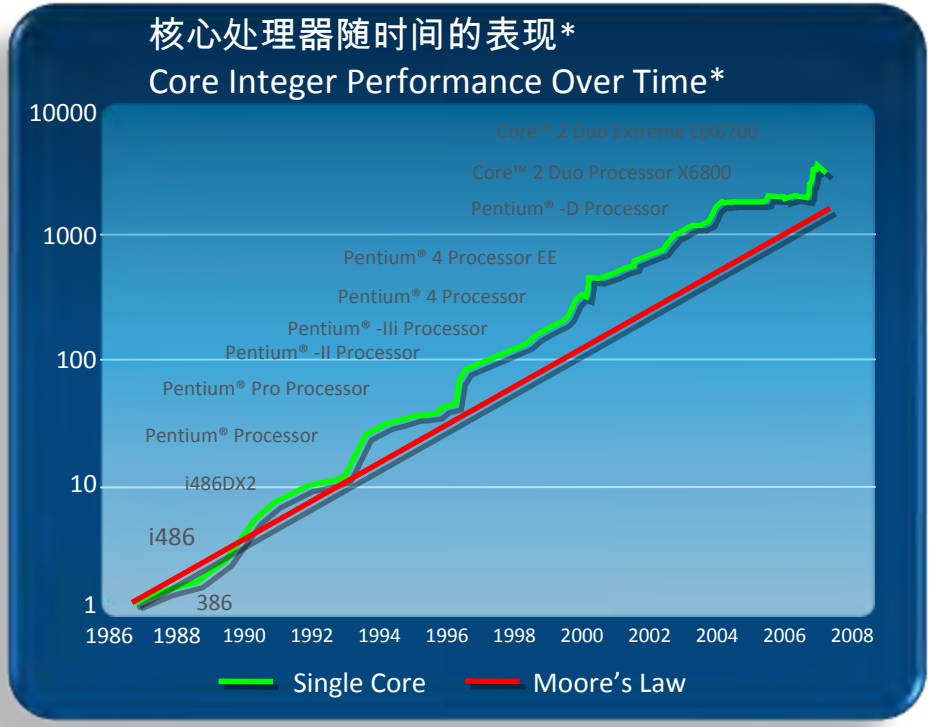
IT设备节约1瓦带来的价值
The value of one watt saved at the IT equipment



摩尔定律
Moore's Law

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy





- 摩尔定律每年都得到验证，伴随着更小更节能的晶体管
  Every year Moore's Law is followed, smaller, more energy-efficient transistors result.
- 30多年来，微型化使能源/晶体管大小降低了一百万倍
  Miniaturization provides 1 million times reduction in energy/transistor size over 30+ years.
- 收益：更小更快的晶体管=> 更快并且更节能的芯片
  Benefits: Smaller, faster transistors => faster AND more energy-efficient chips.

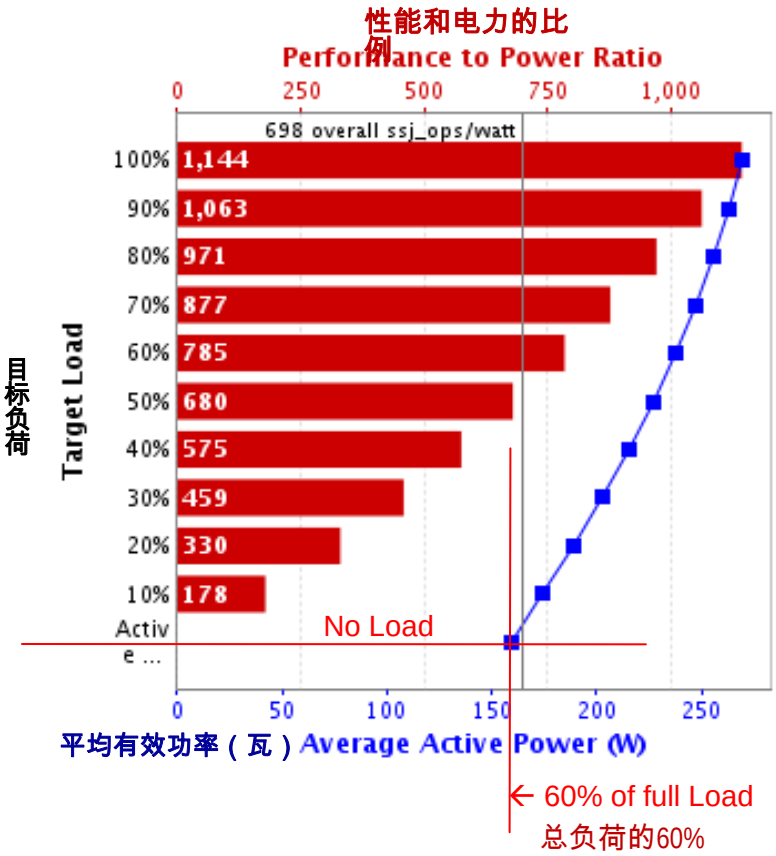
来源：英特尔集团 Source: Intel Corp.

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

IT 能耗模式：服务器 IT Energy Use Patterns: Servers

闲置的服务器最高能消耗全负荷电量的50-60%，如SpecPower 对标值所示。
Idle servers consume as much as 50-60% of power @ full load as shown in SpecPower Benchmarks.

性能 Performance			电量 Power	性能和电力的比例
Target Load	Actual Load	ssj_ops	Average Active Power (W)	Performance to Power Ratio
100%	99.2%	308,022	269	1,144
90%	90.2%	280,134	264	1,063
80%	80.0%	248,304	256	971
70%	69.9%	217,096	247	877
60%	60.1%	186,594	238	785
50%	49.6%	154,075	227	680
40%	39.9%	123,805	215	575
30%	29.9%	92,944	203	459
20%	20.1%	62,364	189	330
10%	10.0%	31,049	174	178
Active Idle		0	160	0
		Σ ssj_ops / Σ power =		698



让不用的服务器停运
Decommission Unused Servers

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

关闭/淘汰低能效或不在使用中的系统
PHYSICALLY RETIRE AN INEFFICIENT OR UNUSED SYSTEM

- **Uptime Institute报道，有15-30%的服务器没有使用**

  Uptime Institute reported 15-30% of servers are on but not being used

- **停运目的包括**

  Decommissioning goals include:
  - 定期存点和监测

    Regularly inventory and monitor
  - 整合/沟汰未合理利用的硬件

    Consolidate/retire poorly utilized hardware

虚拟化和整合化
Virtualize and Consolidate

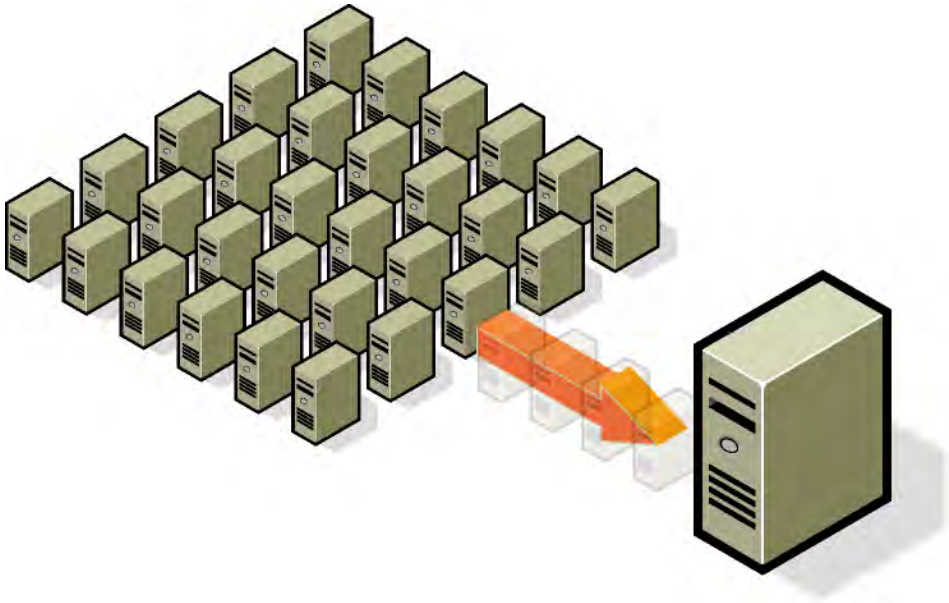
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 在一台“物理的”机器上运行许多“虚拟的”机器

  Run many “virtual” machines on a single “physical” machine
- 整合未充分利用的物理机器，提高利用率

  Consolidate underutilized physical machines, increasing utilization
- 关闭未充分利用的机器，节约能源

  Energy saved by shutting down underutilized machines



虚拟化的云计算可以提供……
Virtualized cloud computing can provide…

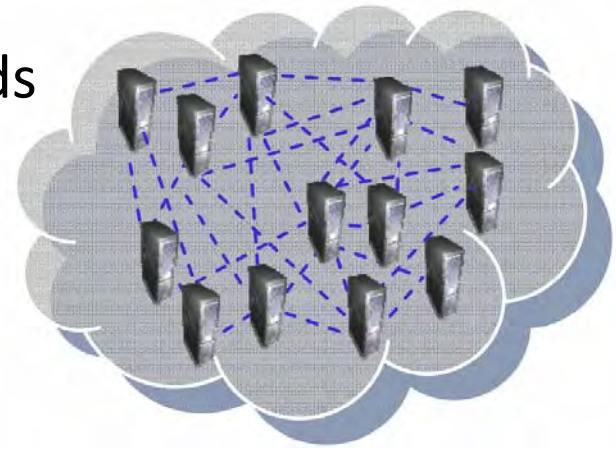
- 在互联网上动态的可扩展的资源

  Dynamically scalable resources over the internet
- 可用于内部或外部使用

  Can be internal or external
- 可用于平衡不同应用的峰值负荷

  Can balancing different application peak loads
- 通常实现高利用率

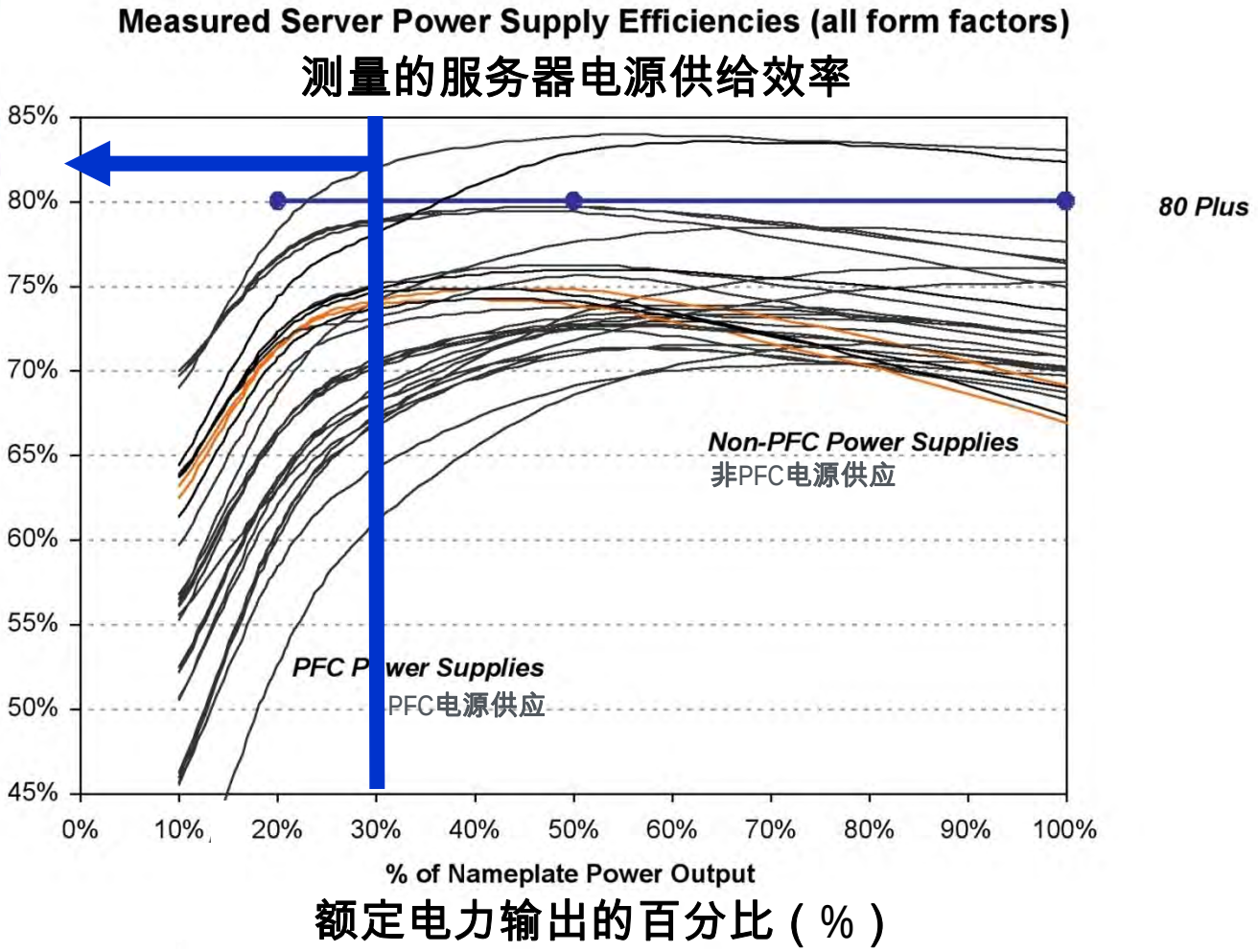
  Typically achieves high utilization rates



利用高效的电源供给
Use Efficient Power Supplies

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

LBNL/EPRI 测量的电源供给效率
LBNL/EPRI measured power supply efficiency



IT系统效率总结.....
IT System Efficiency Summary...

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

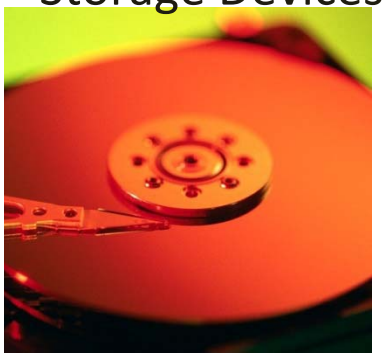
服务器 Servers

- 启动 *电源管理能力*！
  Enable *power management capabilities*!
- 采用“能源之星”服务器
  Use EnergyStar® Servers

电源供给 Power Supplies

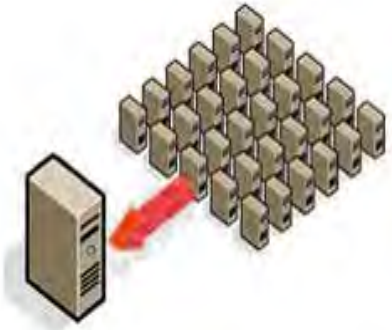
- 重新考虑冗余
  Reconsider Redundancy
- Spec 80 PLUS 或气候节能产品
  Spec 80 PLUS or Climate Savers products

存储设备 Storage Devices



- 将多余的数据下线
  Take superfluous data offline
- 利用精简装置技术
  Use thin provisioning technology

整合Consolidation



- 利用虚拟化
  Use virtualization
- 考虑云服务
  Consider cloud services

Questions? 问题？

报告提纲 AGENDA

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 介绍课程内容和课程讲师
- 数据中心绩效指标和对标
- IT设备和软件效率
- 利用IT节约IT（监测和结果展示）
- 数据中心环境条件
- 气流管理
- 制冷系统
- 电气系统
- 参考资料和研讨会总结

- Introductions to course and instructors
- Performance metrics and benchmarking
- IT equipment and software efficiency
- **Use IT to save IT (monitoring and dashboards)**
- **Data center environmental conditions**
- **Airflow management**
- **Cooling systems**
- **Electrical systems**
- **Resources and Workshop Summary**

利用IT，管理IT

Using IT to Manage IT

数据中心创新的IT应用

Innovative Application of IT in Data Centers

利用IT来管理IT能耗
Use IT to Manage IT Energy

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

利用IT实现节能：
Using IT to Save Energy:

- 大多数运行人员缺乏对数据中心环境的“能见度”

  Most operators lack “visibility” into their data center environment

- 运行人员不能管理他们没有测量的东西

  An operator can’t manage what they don’t measure

利用IT来管理IT能耗
Use IT to Manage IT Energy

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 目标

  Goals:

  - 为监测IT环境提供同样程度的监测和虚拟化物理空间

    Provide the same level of monitoring and visualization of the physical space that exists for monitoring the IT environment
  - 测量并跟踪性能指标

    Measure and track performance metrics
  - 在出现以下问题前就发现问题：

    Spot problems before they result in:

    - 高能源成本

      High energy cost
    - 停机时间

      Down time

LBNL无线传感装置
LBNL Wireless sensor installation

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- ✓ LBNL安装了800多个点传感网络
  LBNL installed 800+ point sensor network.
- ✓ 用于测量 Measures:
  - 温度 Temperature
  - 湿度 Humidity
  - 压力（地板下）
    Pressure (under floor)
  - 电功率 Electrical power
- ✓ 提供实时反馈和历史追踪
  Presents real-time feedback and historic tracking
- ✓ 基于经验数据，而不是直觉，进行优化
  Optimize based on empirical data, not intuition

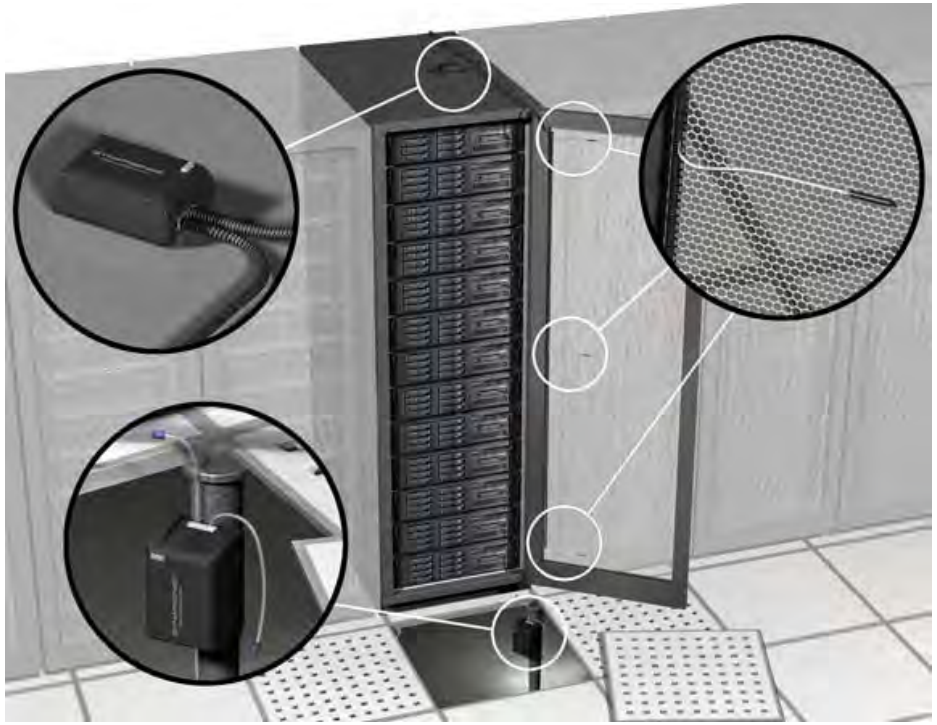
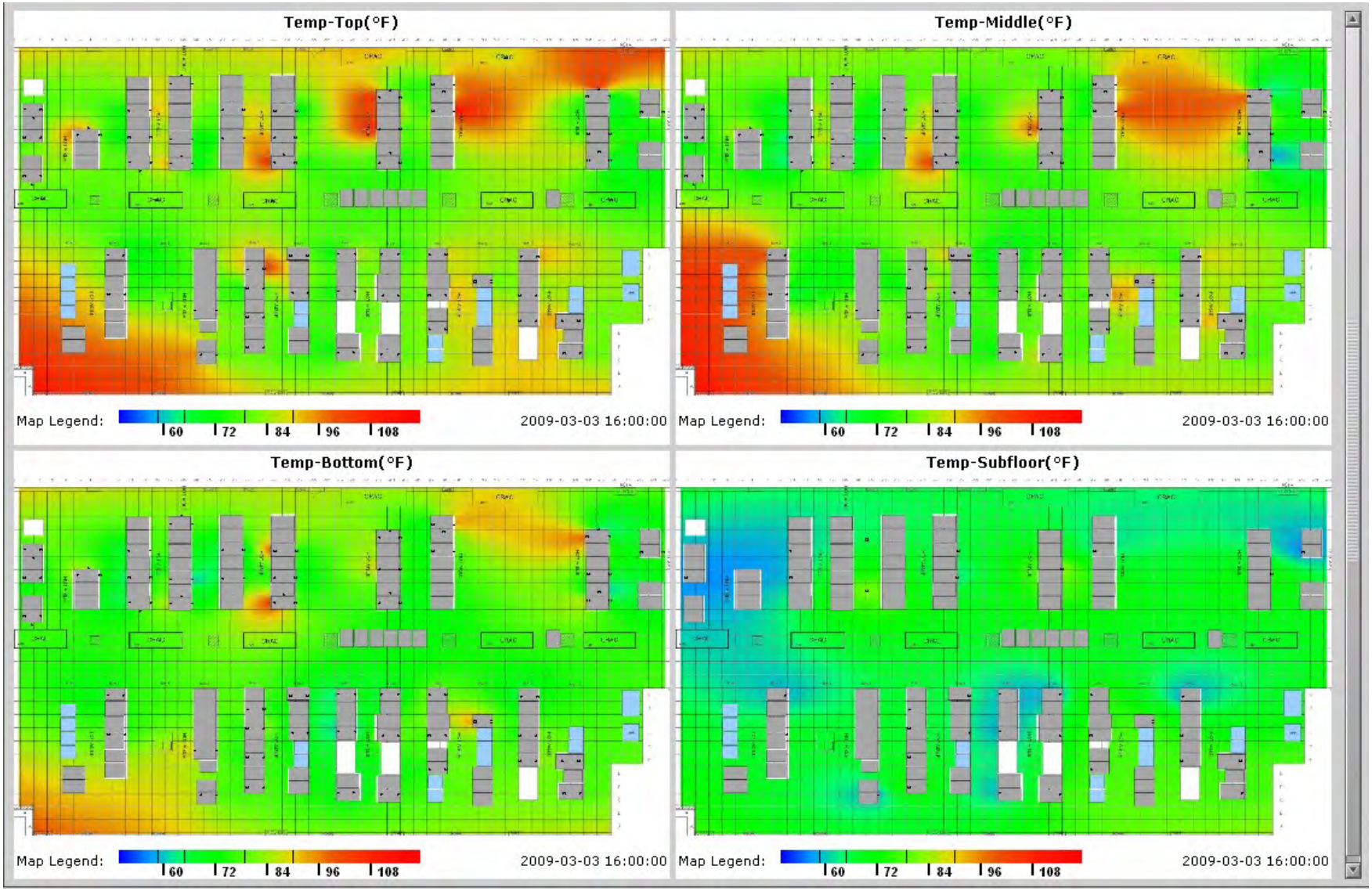


Image: SynapSense

可视化技术日益成熟
Visualization getting much better

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



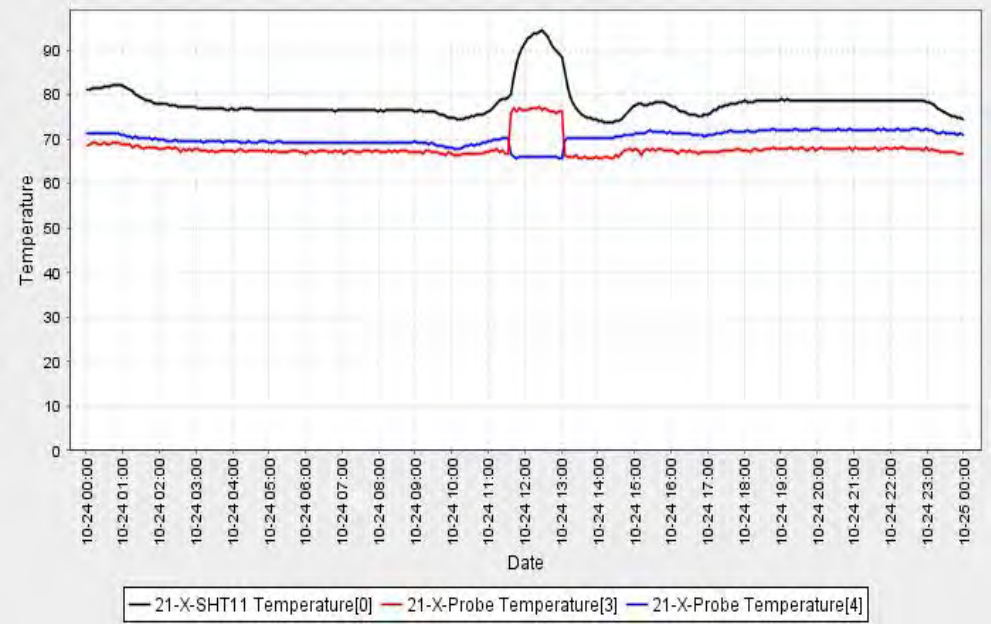
SynapSense™

反馈提供的帮助
Feedback continues to help

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

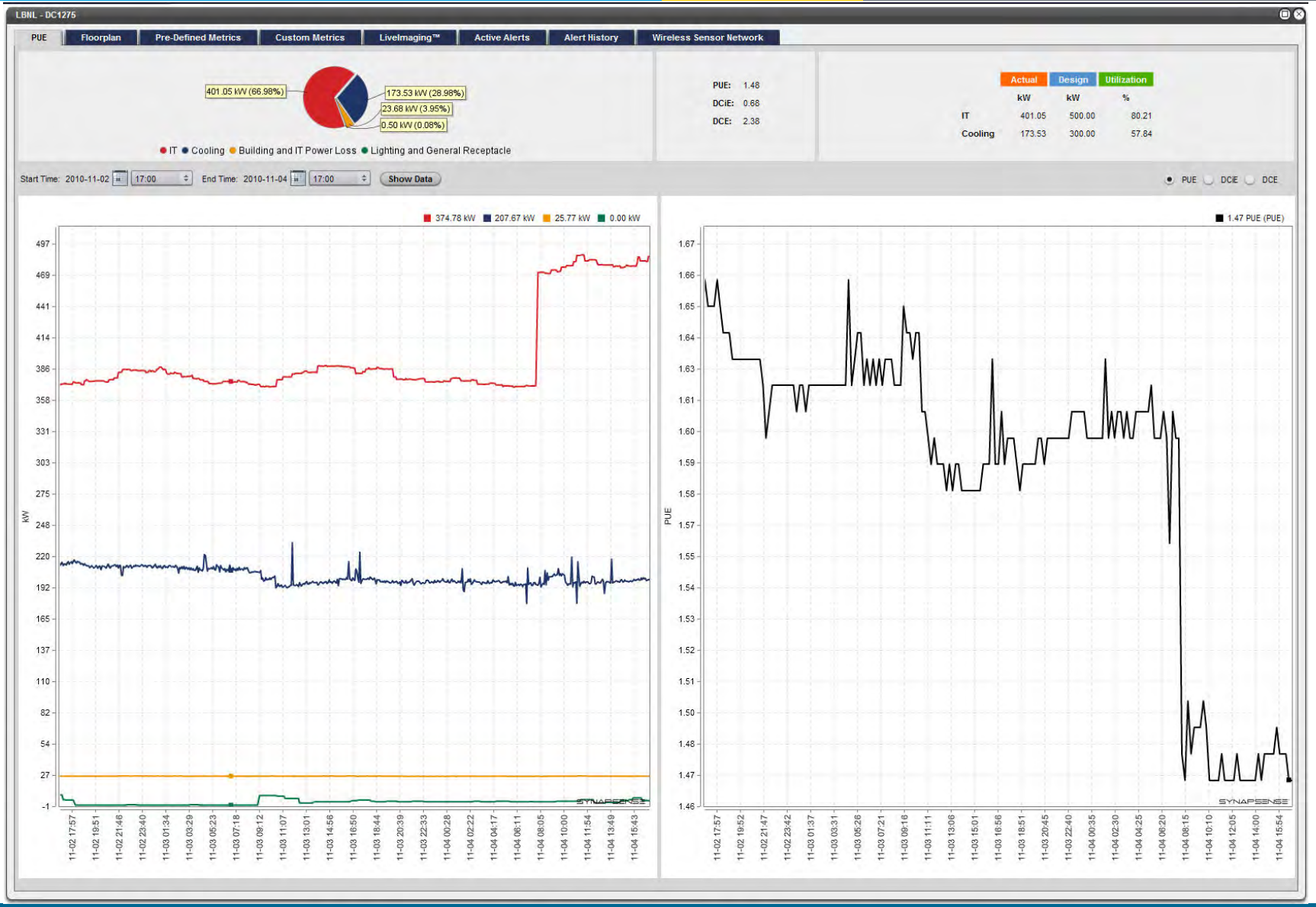
实时反馈可发现冷通道气流的阻碍！

Real-time feedback identified cold aisle air flow obstruction!



实时电源使用效率（PUE）展示
Real-time PUE Display

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



PUE计算图表
PUE Calculation Diagram

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

利用内置的IT服务器设备温度传感器控制数据中心的制冷

Control data center air conditioning using the *built-in* IT server-equipment temperature sensors

英特尔示范
Intel Demonstration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- **典型情况下，数据中心制冷设备将循环空气温度作为控制变量**

  Typically, data center cooling devices use *return air temperature* as the control-variable

  - 美国采暖制冷与空调工程师学会（ASHRAE）和IT制造商都认为IT设备进气温度是关键的运行参数

    ASHRAE and IT manufacturers agree IT equipment inlet air temperature is the key operational parameter
  - 最优控制的困难

    Optimum control difficult
- 服务器进气温度可从ICT网络上获得

  Server inlet air temperature is available from ICT network

  - 智能平台管理接口（IPMI）或

    Intelligent Platform Management Interface (IPMI) or
  - 简单网络管理协议（SNMP）

    Simple network management protocol (SNMP)

英特尔示范
Intel Demonstration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 示范显示：

  Demonstration showed:

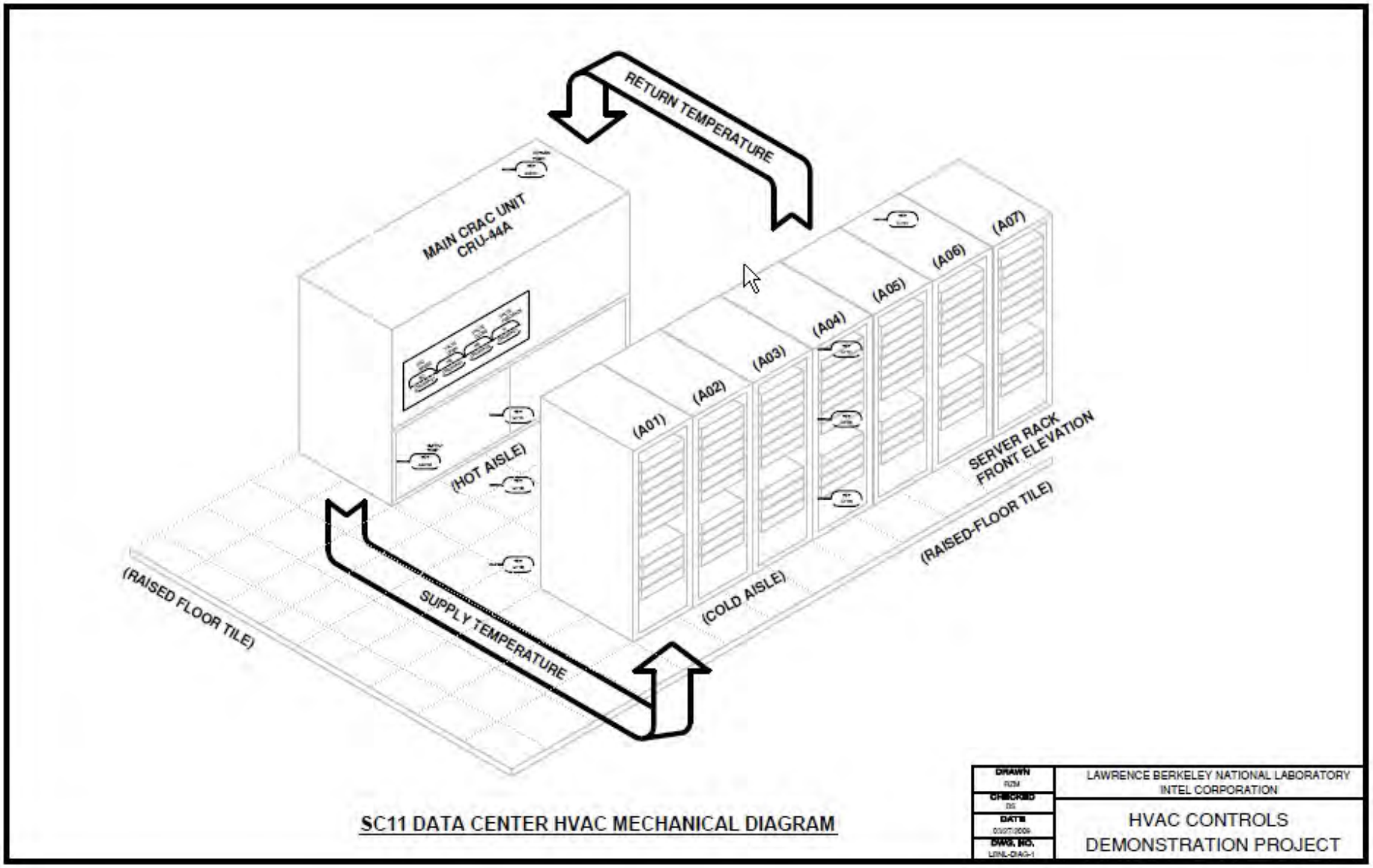
  - 服务器可设施的控制系统提供温度数据

    Servers can provide temperature data to facilities control system
  - 考虑到服务器进气温度，设施的控制改善了温度控制和效率

    Given server inlet temperature, facility controls improved temperature control and efficiency
  - 在没有明显干扰或没有对系统进行重新配置的情况下，实现了高效的通信和控制

    Effective communications and control accomplished without significant interruption or reconfiguration of systems

英特尔数据中心的暖通空调：
Intel Data Center HVAC:



情况展示
Dashboards

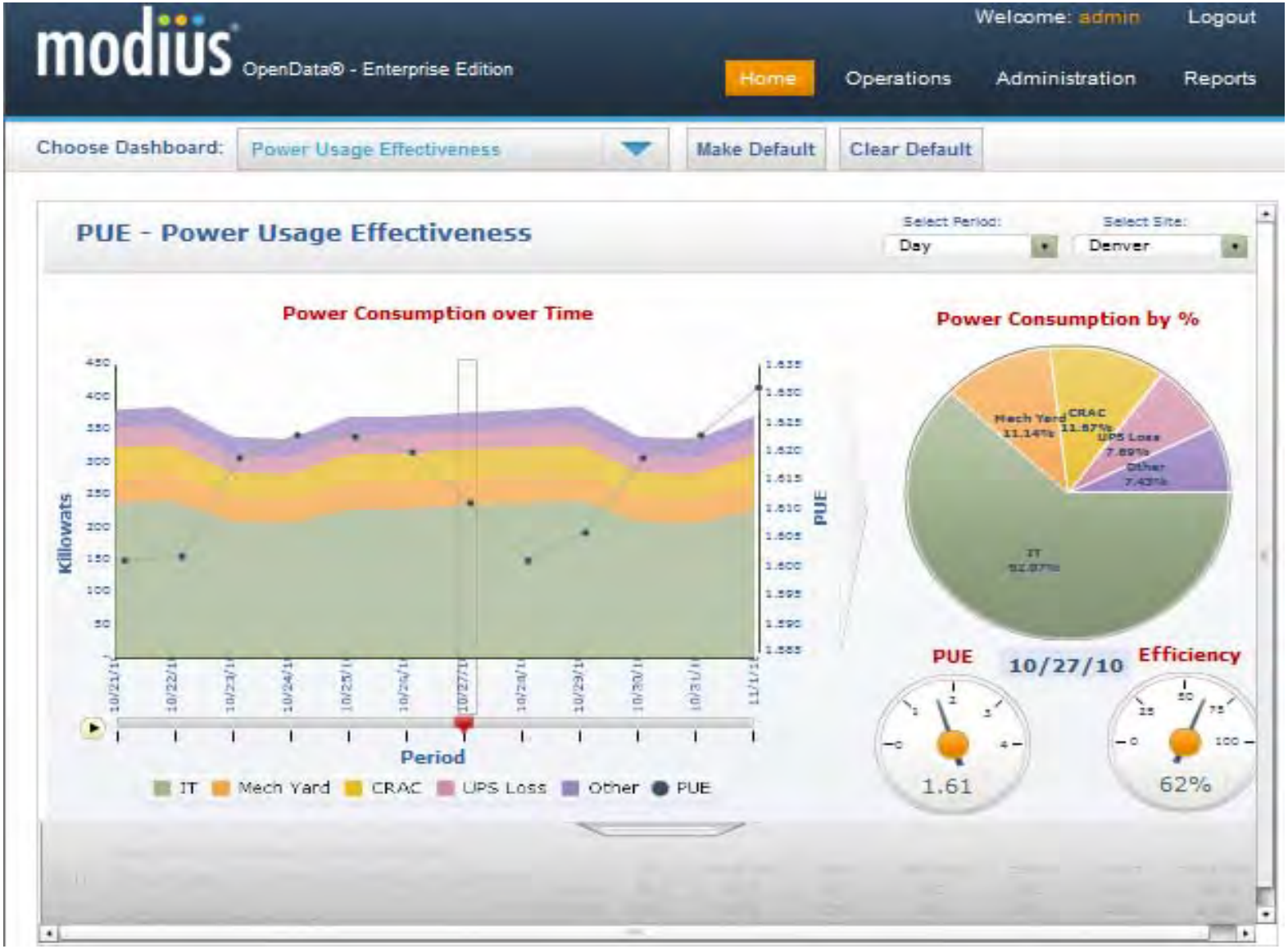
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

情况展示盘可以显示多个系统的信息，对数据中心的性能进行监测和维护
Dashboards can display multiple systems' information for monitoring and maintaining data center performance

- 提供IT和暖通空调系统性能一览图
  Provide IT and HVAC system performance at a glance
- 识别运行的问题
  Identify operational problems
- 基线能耗和对标性能
  Baseline energy use and benchmark performance
- 观察变化产生的结果
  View effects of changes
- 为综合决策提供信息和支持
  Inform integrated decisions

能效展示盘示例
Efficiency Dashboard Example:

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



利用IT来管理IT能耗：总结
Use IT to Manage IT Energy: Summary

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 评估监测系统，增强运行和控制的能力

  Evaluate monitoring systems to enhance operations and controls
- 使用展示盘，对能效进行管理和维护

  Install dashboards to manage and sustain energy efficiency.

Questions? 问题？

报告提纲 AGENDA

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 介绍课程内容和课程讲师
- 数据中心绩效指标和对标
- IT设备和软件效率
- 利用IT节约IT（监测和展示盘）
- **数据中心环境条件**
- **气流管理**
- **制冷系统**
- **电气系统**
- **参考资料和研讨会总结**

- Introductions to course and instructors
- Performance metrics and benchmarking
- IT equipment and software efficiency
- Use IT to save IT (monitoring and dashboards)
- **Data center environmental conditions**
- **Airflow management**
- **Cooling systems**
- **Electrical systems**
- **Resources and Workshop Summary**

环境条件

Environmental Conditions

暖通空调能耗的主要驱动力是什么？

What are the main HVAC Energy Drivers?

- IT负荷 IT Load
- 气候 Climate
- 房间温度和湿度

  Room temperature and humidity
  - 大多数数据中心过度冷却，并有湿度控制问题

    Most data centers overcooled and have humidity control issues
  - 人体舒适度不应该成为驱动因素

    Human comfort should not be a driver

环境条件
Environmental Conditions

ASHRAE的热力指南：

ASHRAE's Thermal Guidelines:

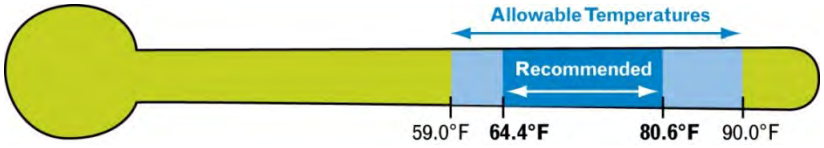
- 为IT和设施员工提供共同理解的基础

  Provide common understanding between IT and facility staff.
- 得到IT制造商的认可

  Endorsed by IT manufacturers
- 带来较大节能量——尤其是当使用节电装置时

  Enables large energy savings - especially when using economizers.
- 建议的温度区间是18˚C to 27˚C（80.6°F），而"可允许"的温度则更高

  Recommends temperature range of 18˚C to 27˚C (80.6°F) with "allowable" much higher



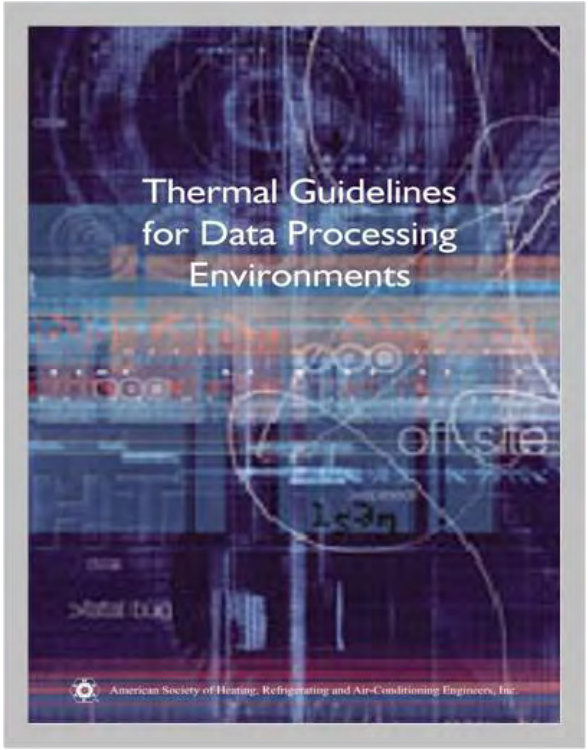
环境条件
Environmental Conditions

- 新的（2011）ASHRAE指南
  New (2011) ASHRAE Guidelines
  - 六个等级的设备，确定了更宽的可允许范围，从32°C to 45°C (113°F)

    Six classes of equipment identified with wider allowable ranges from 32°C to 45°C (113°F)
  - 为在建议区间以外（并在允许范围内）的运行状况提供更多的理由

    Provides more justification for operating above the recommended limits (in the allowable range)
  - 提供更大的湿度区间

    Provides wider humidity ranges



2011 ASHRAE 热力指南
2011 ASHRAE Thermal Guidelines

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

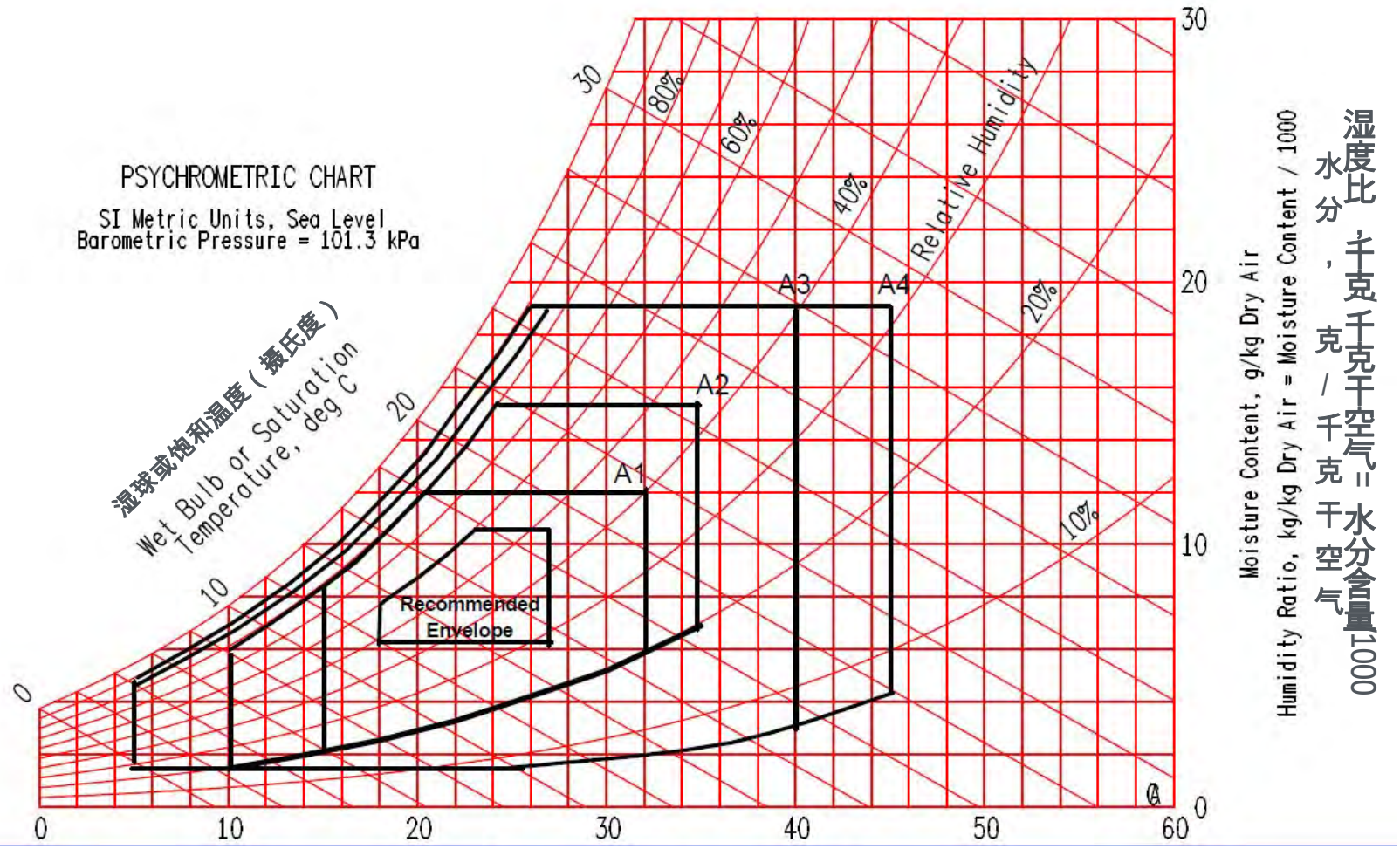
Classes (a)	Equipment Environmental Specifications 设备环境规范							
	Product Operations (b)(c)					Product Power Off (c) (d)		
	Dry-Bulb Temperature (˚C) (e) (g)	Humidity Range, non-Condensing (h) (i)	Maximum Dew Point (˚C)	Maximum Elevation (m)	Maximum Rate of Change(˚C/hr) (f)	Dry-Bulb Temperature (˚C)	Relative Humidity (%)	Maximum Dew Point (˚C)
Recommended (Applies to all A classes; individual data centers can choose to expand this range based upon the analysis described in this document) 建议的								
A1 to A4	18 to 27	5.5ºC DP to 60% RH and 15ºC DP						
Allowable 可允许的								
A1	15 to 32	20% to 80% RH	17	3050	5/20	5 to 45	8 to 80	27
A2	10 to 35	20% to 80% RH	21	3050	5/20	5 to 45	8 to 80	27
A3	5 to 40	-12˚C DP & 8% RH to 85% RH	24	3050	5/20	5 to 45	8 to 85	27
A4	5 to 45	-12˚C DP & 8% RH to 90% RH	24	3050	5/20	5 to 45	8 to 90	27
B	5 to 35	8% RH to 80% RH	28	3050	NA	5 to 45	8 to 80	29
C	5 to 40	8% RH to 80% RH	28	3050	NA	5 to 45	8 to 80	29

2011年数据处理环境的热力指南——扩大的数据中心等级和利用指南。 ASHRAE 技术委员会TC9.9编写的白皮书。

2011 Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage Guidance. White paper prepared by ASHRAE Technical Committee TC 9.9

2011 ASHRAE可允许区间
2011 ASHRAE allowable ranges

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



干球温度

Dry Bulb Temperature

2011 ASHRAE 热力指南
2011 ASHRAE Thermal Guidelines

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

在提高的（但可允许的）温度下，增加的故障率的可能性，ASHRAE作出的关键结论是：

ASHRAE's key conclusion when considering potential for increased failures at higher (allowable) temperatures:

空气侧和水侧的节约装置的预测显示,对于绝大多数美国和欧洲城市来说，其故障率与一个传统数据中心在20 ℃的恒温状态下的故障率是相当的。”

“For a majority of US and European cities, the air-side and water-side economizer projections show failure rates that are very comparable to a traditional data center run at a steady state temperature of 20°C.”

环境条件：总结
Environmental conditions: Summary

- 一个过冷的数据中心= 能效机会的存在

  A cold data center = efficiency opportunity
- 基于老技术的观念，带来了过冷的数据中心，以及很窄的湿度区间——*这需要改变*

  Perceptions, based on old technology lead to cold data centers with tight humidity ranges – *this needs to change*
- 许多IT制造商的设计是为比ASHRAE指南更艰苦的条件准备的

  Many IT manufacturers design for harsher conditions than ASHRAE guidelines
- 数据中心的设计考虑IT设备的性能—而不是人的舒适度

  Design Data Centers for IT equipment performance - *not people comfort*.
- 在提高温度前必须考虑空气管理问题

  Must address air management before raising temperature

Questions? 问题？

报告提纲 AGENDA

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 介绍课程内容和课程讲师
- 数据中心绩效指标和对标
- IT设备和软件效率
- 利用IT节约IT（监测和展示盘）
- 数据中心环境条件
- **气流管理**
- **制冷系统**
- **电气系统**
- **参考资料和研讨会总结**

- Introductions to course and instructors
- Performance metrics and benchmarking
- IT equipment and software efficiency
- Use IT to save IT (monitoring and dashboards)
- Data center environmental conditions
- **Airflow management**
- **Cooling systems**
- **Electrical systems**
- **Resources and Workshop Summary**

气流管理

Airflow Management

Effective Application and Use in Data Centers

空气管理： LBNL的早期
Air Management: The Early Days at LBNL

很冷，但是到处都有热的区域
It was cold but hot spots were everywhere

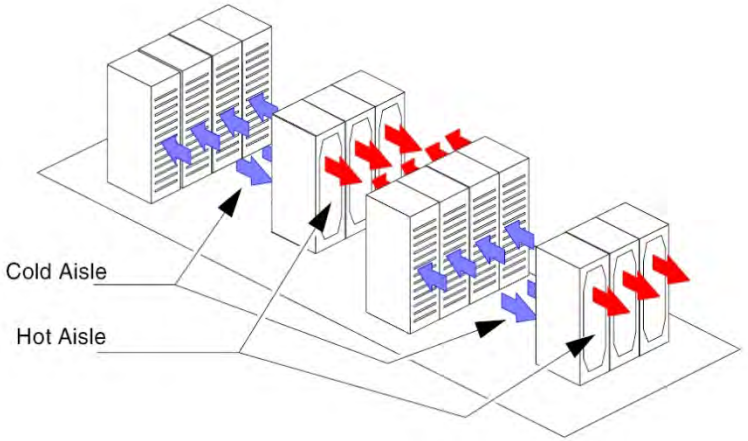
利用风扇来改变空气方向
Fans were used to redirect air

大空隙的铺砖增加空气流动但降低了空气压力
High flow tiles reduced air pressure

空气管理
Air Management

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 典型情况下，空气流动多于所需
  Typically, more air circulated than required
- 空气混合和“气流短路”导致：
  Air mixing and short circuiting leads to:
  - 低供给温度
    Low supply temperature
  - 低 Delta T
    Low Delta T
- 利用热通道和冷通道
  Use hot and cold aisles
- 改善热通道和冷通道的阻断
  Improve isolation of hot and cold aisles
  - 降低风机能耗
    Reduce fan energy
  - 改善空调效率
    Improve air-conditioning efficiency
  - 提高制冷容量
    Increase cooling capacity



热通道/冷通道的配置降低了进气口和排气口混合度，提高了能效

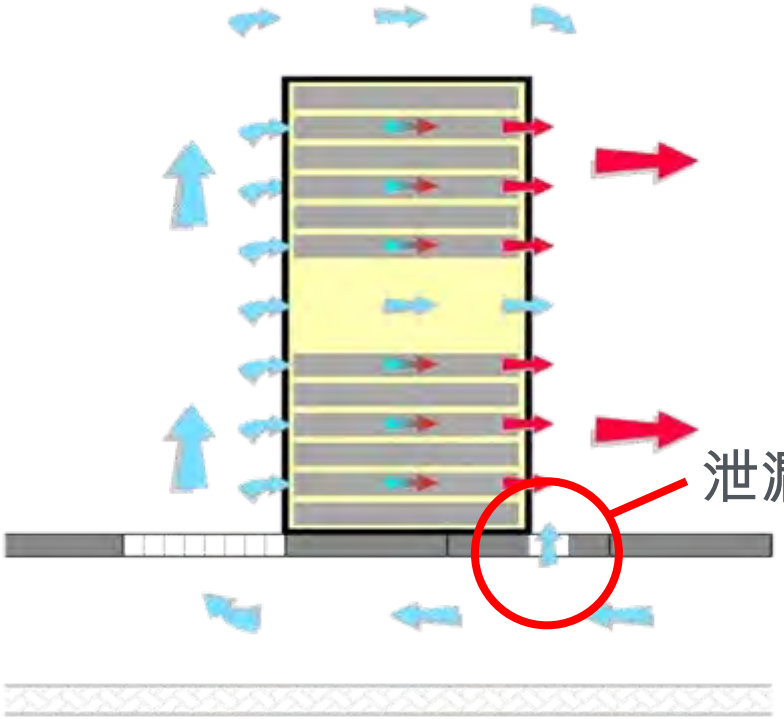
Hot aisle / cold aisle configuration decreases mixing of intake & exhaust air, promoting efficiency.

减少旁路和再循环
Reduce Bypass and Recirculation

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

旁通空气/短路循环……

Bypass Air / Short-Circuiting…

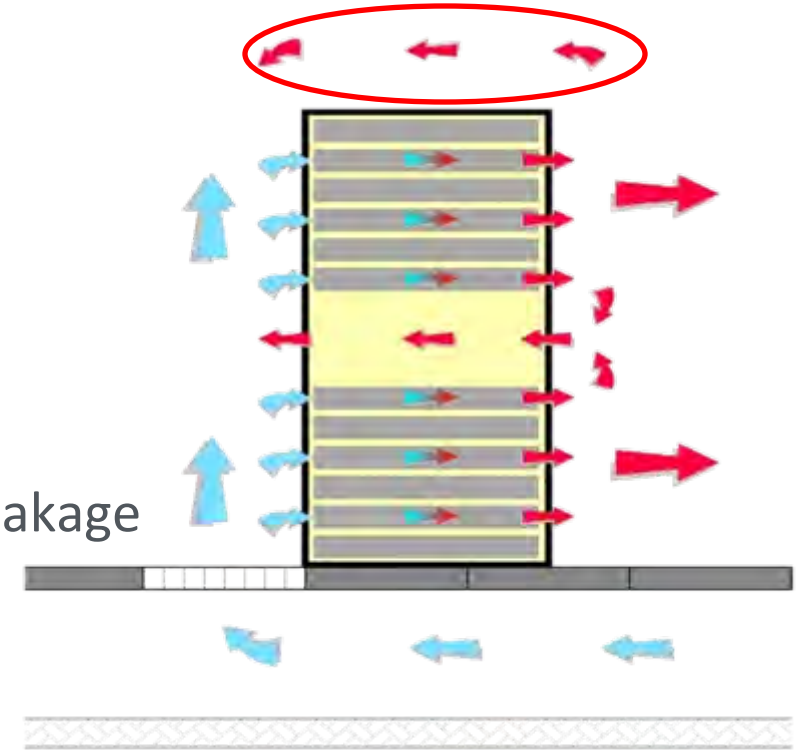


浪费制冷容量

Wastes cooling capacity.

再循环……

Recirculation…



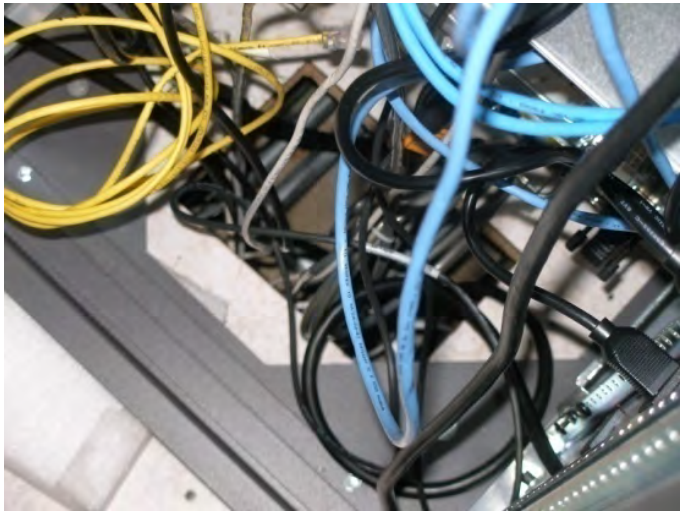
增加了服务器的进气温度

Increases inlet temperature to servers.

保护加高地板的密封
Maintain Raised-Floor Seals

对架高的地板的所有潜在的泄漏，进行维修保养

Maintain sealing of all potential leaks in the raised floor plenum.



未密封的电线穿墙

Unsealed cable penetration

密封的电线穿墙

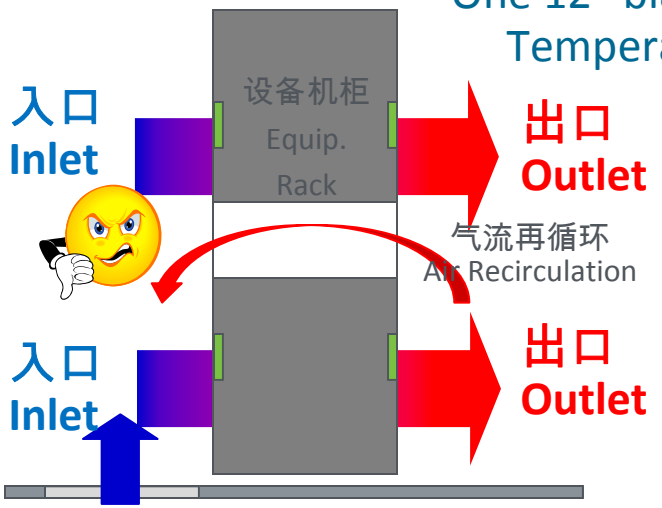
Sealed cable penetration

管理挡板
Manage Blanking Panels

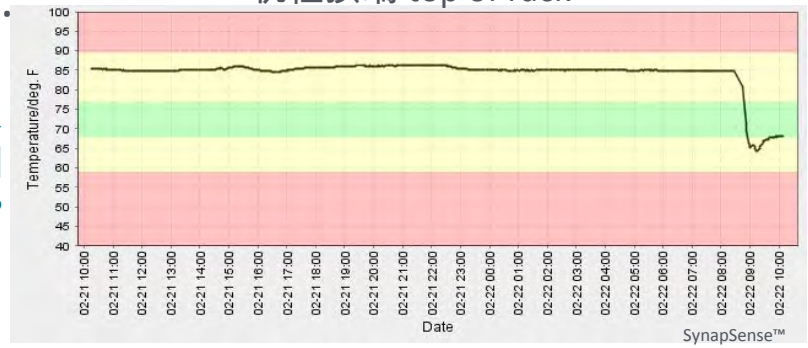
- 管理服务器挡板和侧板是非常重要的。
  Managing server blanking and side panels is very important.
- 通道之间的*任何*开口都将降低热空气和冷空气的分离程度
  Any opening between the aisles will degrade the separation of hot and cold air.

➢ 对服务器挡板和侧板进行维护
Maintain server blanking and side panels.

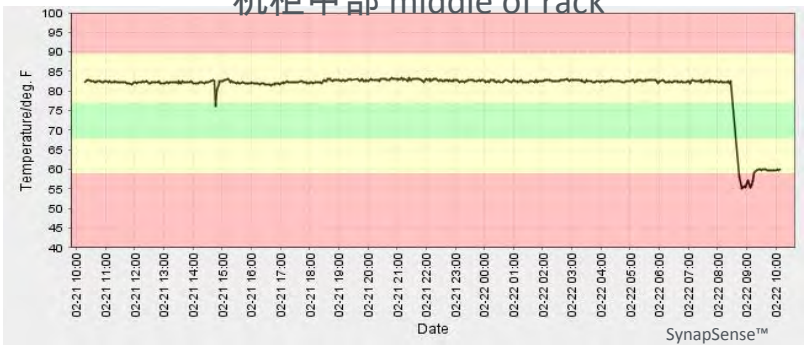
增加一块12英寸的挡板，
使温度降低了约20度
One 12” blanking panel added
Temperature dropped ~20°



机柜顶端 top of rack



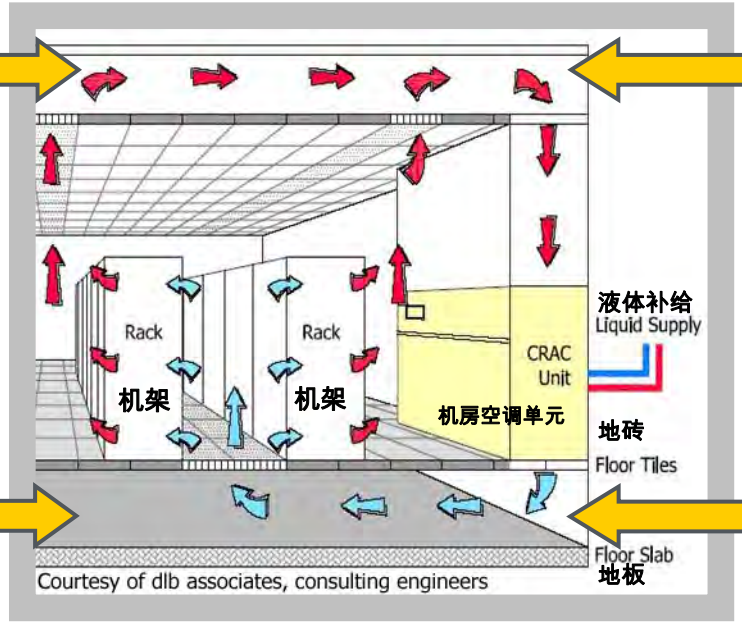
机柜中部 middle of rack



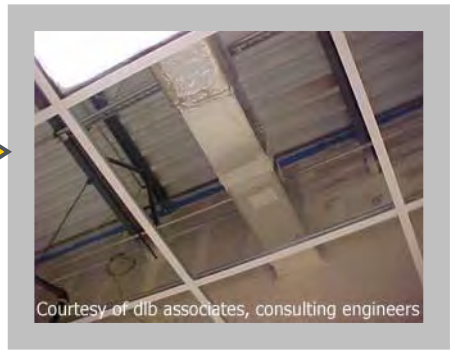
减少气流阻力和拥堵
Reduce Airflow Restrictions & Congestion

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

拥堵的地板和天花板各层
Congested Floor & Ceiling Cavities

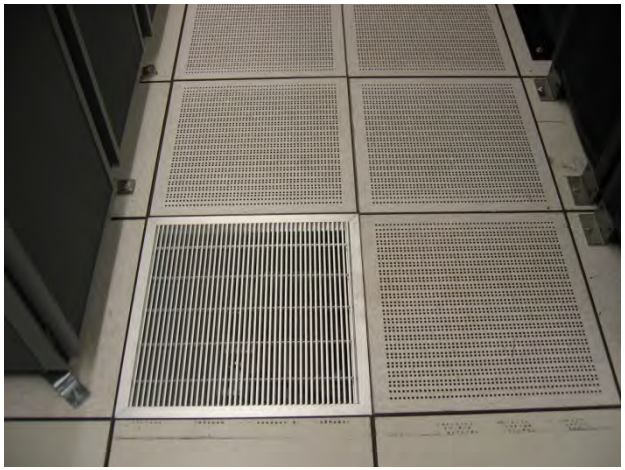


考虑拥堵对气流模式造成的影响
Consider The Impact That Congestion Has On The Airflow Patterns

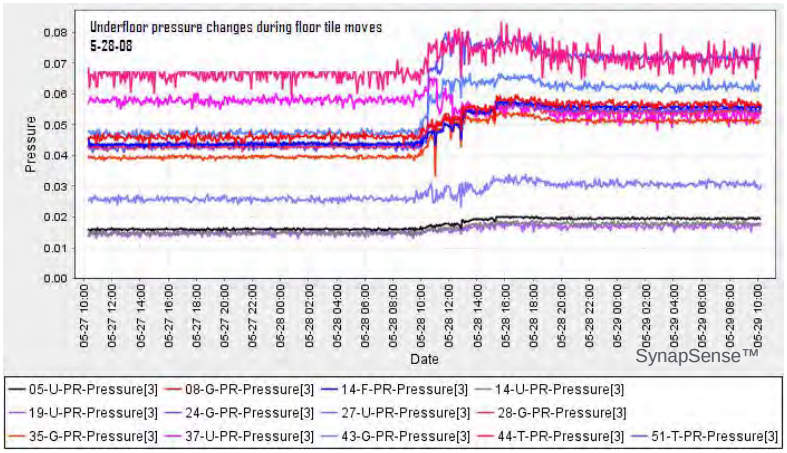


清空地板和天花板隔层
Empty Floor & Ceiling Cavities

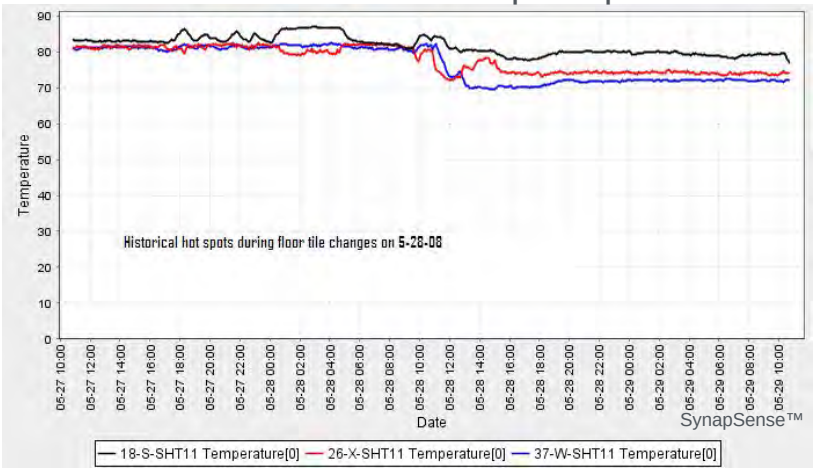
调整地砖
Tune Floor Tiles



地板下面压力under-floor pressures



机架顶方温度rack-top temperatures

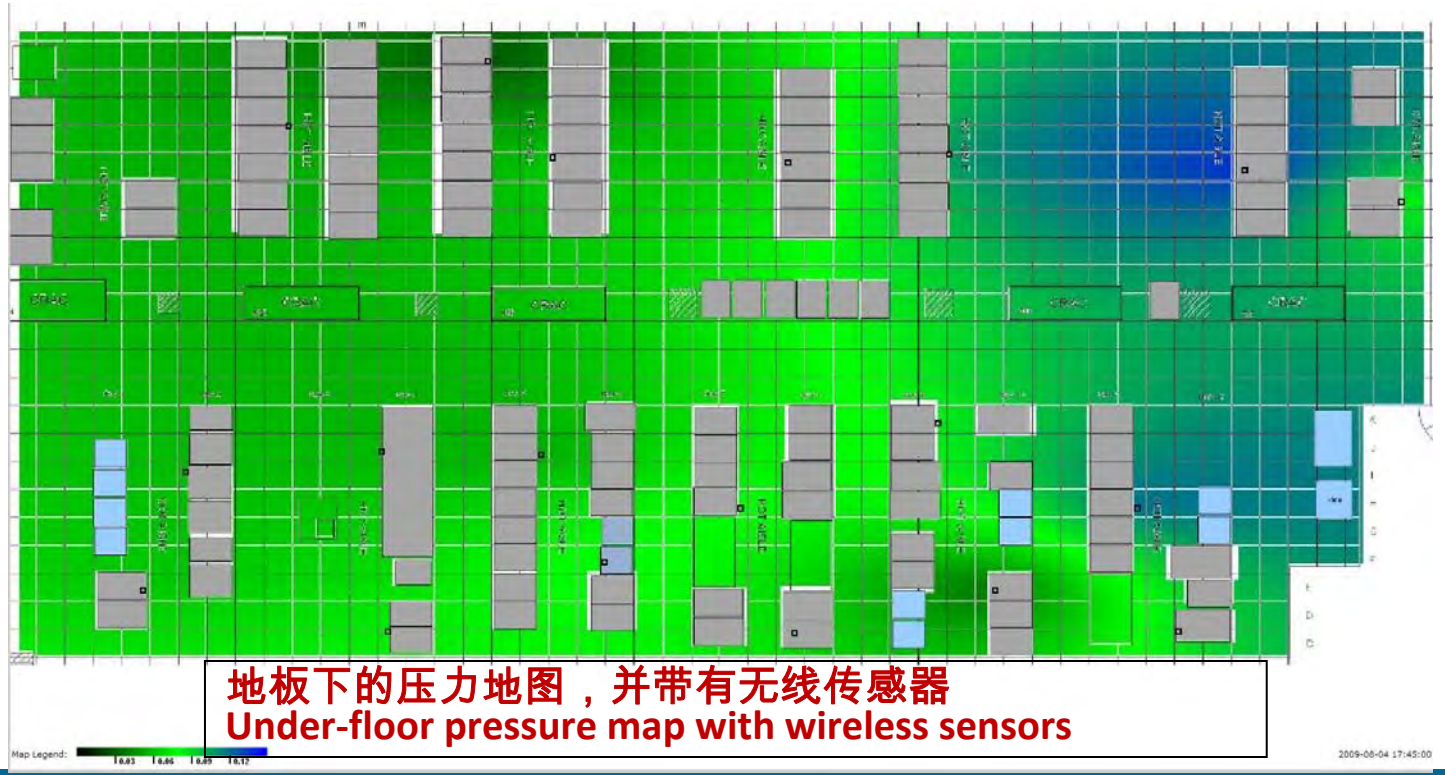


- 过多有透过性的地砖
  Too many permeable floor tiles
- 如果优化气流 if airflow is optimized
  - 地板下面压力增加 ↑
    under-floor pressure ↑
  - 机架顶方温度降低 ↓
    rack-top temperatures ↓
  - 数据中心容量提高
    data center capacity increases
- 测量和虚拟化可以帮助调节
  Measurement and visualization assisted tuning process

解决气流平衡
Resolve Airflow Balancing

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

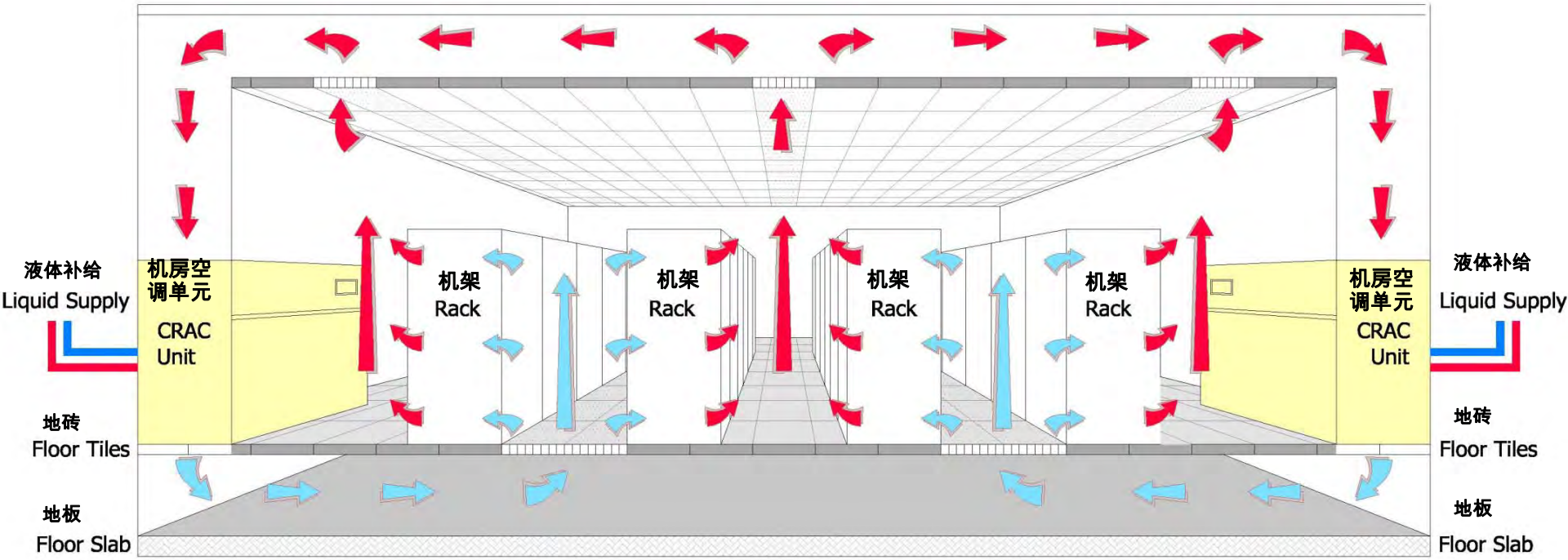
- 气流的优化需要对气流进行平衡
  BALANCING is required to optimize airflow.
- 新的IT设备或暖通空调设备需要重新进行气流平衡
  Rebalancing needed with new IT or HVAC equipment
- *只在*冷通道内安装多孔的地砖
  Locate perforated floor tiles *only* in cold aisles



地板下的压力地图，并带有无线传感器
Under-floor pressure map with wireless sensors

下一步：回风室
Next step: Return-Air Plenum

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



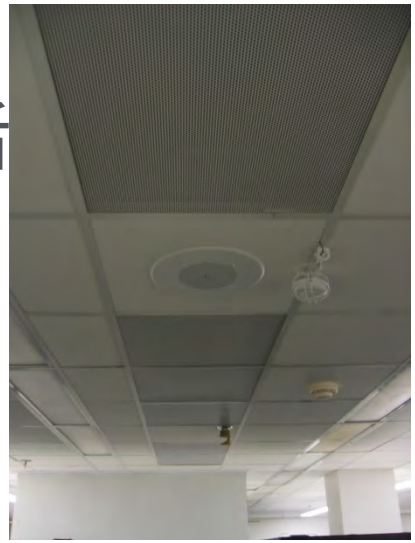
回风室
Return Air Plenum

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 高架送风被转化为热风回流
  Overhead plenum converted to hot-air return
- 机房空调进风口延长到高架
  CRAC intakes extended to overhead
- 将寄存器放置到热通道中
  Return registers placed over hot aisle

改进前
Before

改进后
After

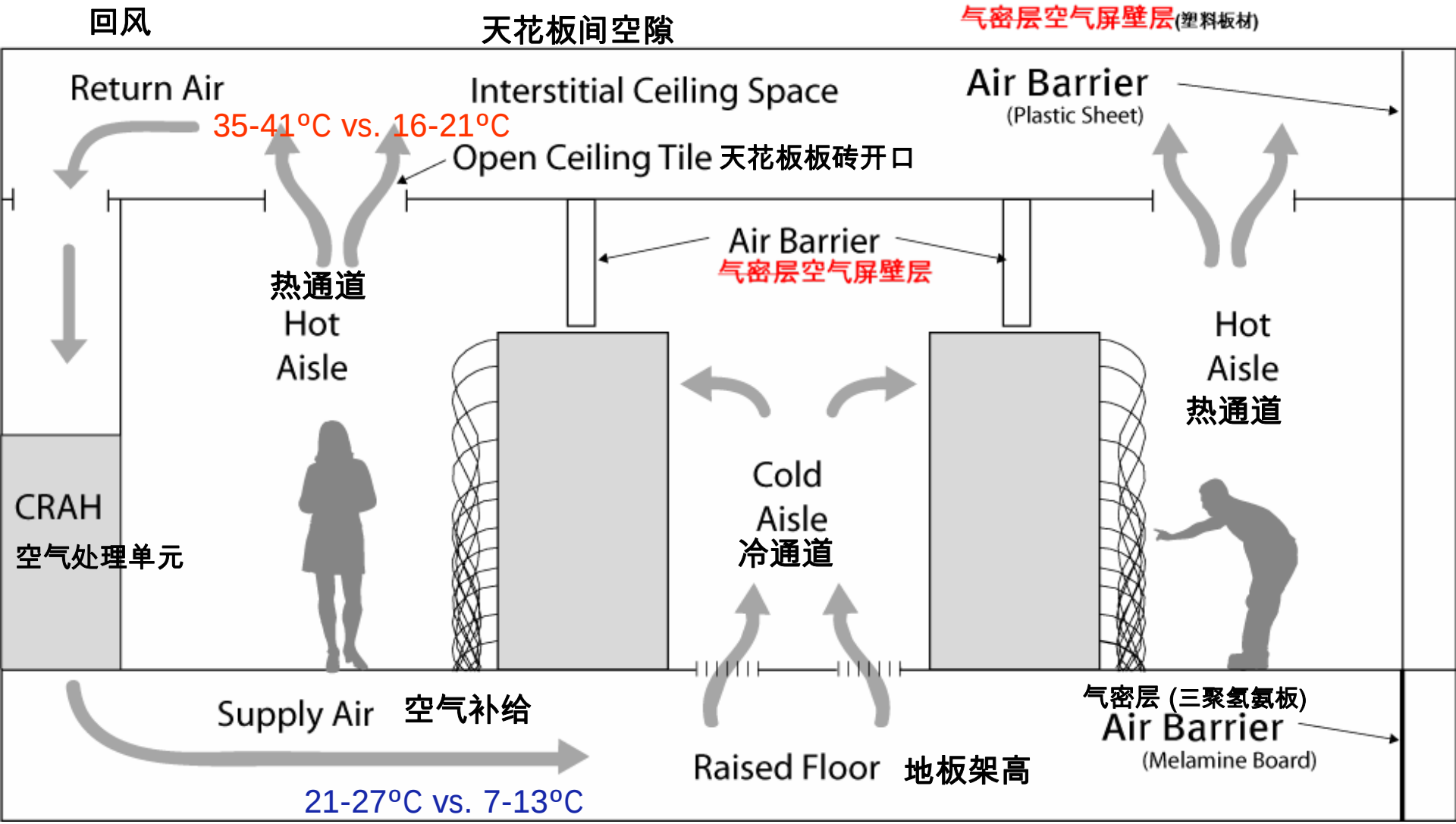


对热冷绝缘添加空气帘
Add Air Curtains for Hot/Cold Isolation

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

分开冷热通道
Isolate Cold and Hot Aisles

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



无需架高地板
Raised Floor Not Required

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

具有冷热气分流功能的区域性制冷系统，可辅助或取代地板制冷系统

Localized air cooling systems with hot and cold isolation can supplement or replace under-floor systems

例子包括：

Examples include:

- **行级制冷系统**

  Row-based cooling units

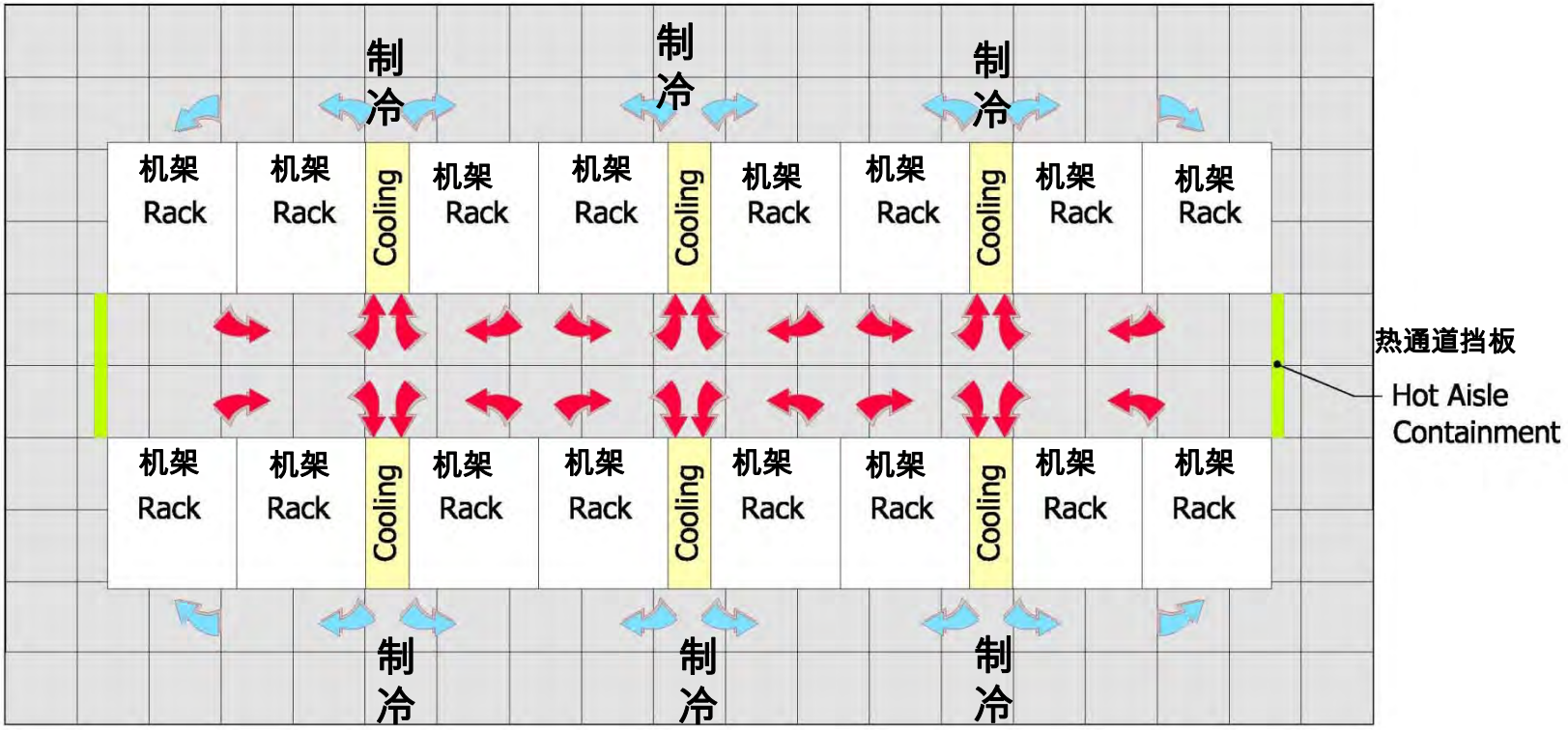
- **可架于机架的热交换器**

  Rack-mounted heat exchangers

- **“预先设计”的冷热分离系统**

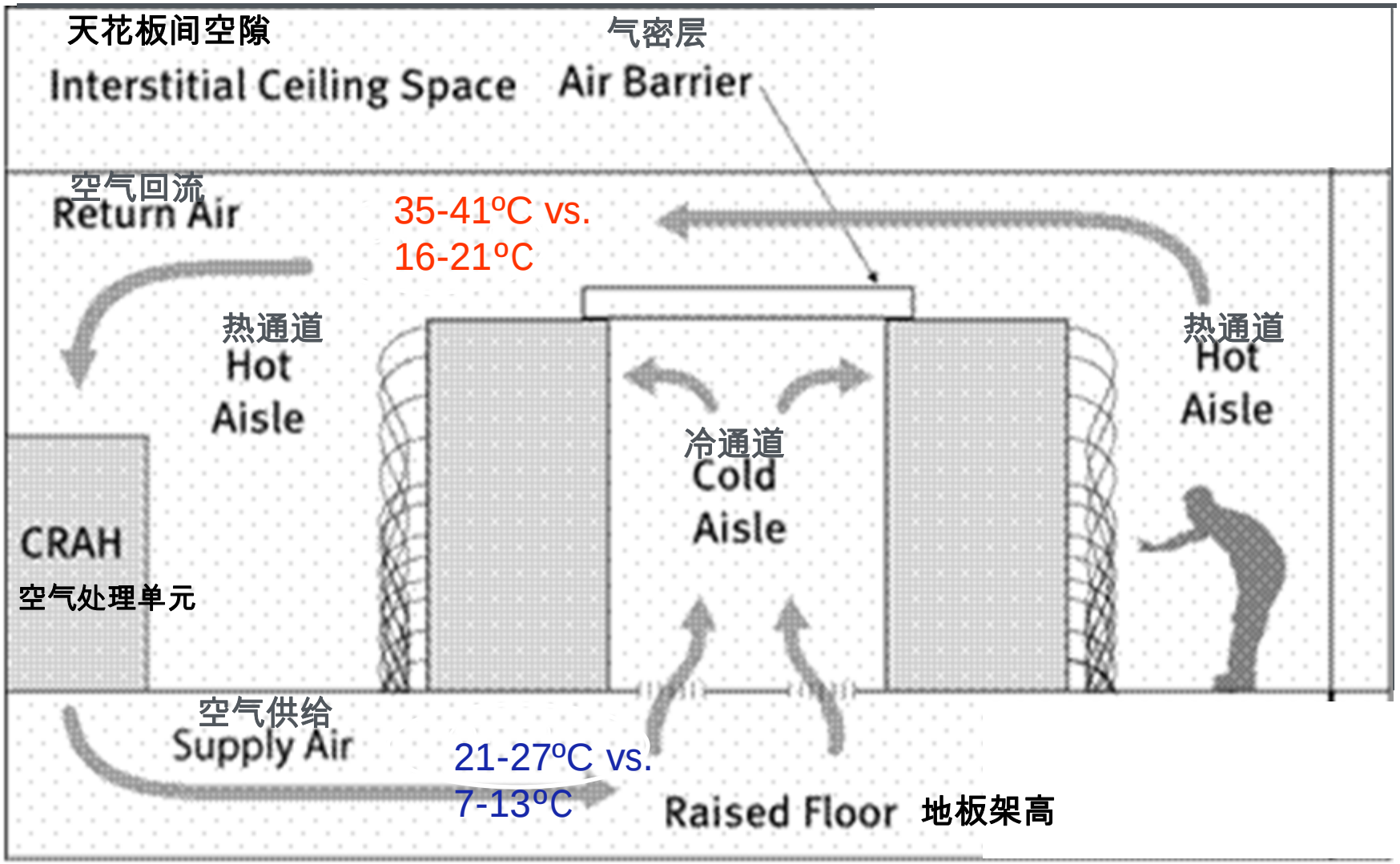
  Both options “Pre-engineer” hot and cold isolation

例子：行级制冷系统
Example: Row-based Cooling



最佳情景 - 隔绝热通道和冷通道
Best Scenario - Isolate Cold and Hot

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



回顾：气流管理基本概念
Review: Airflow Management Basics

气流管理技巧:

Air management techniques:

- 对地板漏气的地方做弥封处理(如电线穿墙)
  Seal air leaks in floor (e.g. cable penetrations)
- 机架使用挡板以阻止空气二次循环
  Prevent recirculation with blanking panels in racks
- 对使用的地砖种类进行管理(如热通道不用多孔砖)
  Manage floor tiles (e.g. no perforated tiles in hot aisle)
- 加强冷热空气分流的处理(如回风区、隔热帘或完全隔热)
  Improve isolation of hot and cold air (e.g. return air plenum, curtains, or complete isolation)

回顾：气流管理基本概念
Review: Airflow Management Basics

做好分隔处理的好处：Impact of good isolation:

- 减少补给气流的用量

  Supply airflow reduced

  - 风机节能75%以上

    Fan savings up to 75%+

- 提高整体的温度

  Overall temperature can be raised

  - 制冷系统能效提高

    Cooling systems efficiency improves

  - 节约装置有更大的节能潜力(“免费”制冷)

    Greater opportunity for economizer (“free” cooling)

- 制冷容量提高

  Cooling capacity increases

Questions? 问题？

报告提纲 AGENDA

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 介绍课程内容和课程讲师
- 数据中心绩效指标和对标
- IT设备和软件效率
- 利用IT节约IT（监测和展示盘）
- 数据中心环境条件
- 气流管理
- **制冷系统**
- **电气系统**
- **参考资料和研讨会总结**

- Introductions to course and instructors
- Performance metrics and benchmarking
- IT equipment and software efficiency
- Use IT to save IT (monitoring and dashboards)
- Data center environmental conditions
- Airflow management
- **Cooling systems**
- **Electrical systems**
- **Resources and Workshop Summary**

制冷系统

Cooling systems

去除数据中心的热量

Removing heat from data centers

机房空调单元与空气处理单元

Computer Room Air Conditioners (CRACs) and Air Handlers (CRAHs)

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- **机房空调单元**

  CRAC units

  – 风机、直接膨胀式冷线圈及冷冻剂压缩机

  Fan, direct expansion (DX) cooling coil, and refrigerant compressor

- **空气处理单元**

  CRAH units

  – 空气处理机-风机与冷却水线圈

  Air handlers - fan and chilled water coil

  – 常见于有冷冻设备的大型工厂

  Typically in larger facilities with a chiller plant

- **这二种设备通常会配备加湿设备，并透过二次加热来除湿**

  Both often equipped with humidifiers and reheat for dehumidification

- **这二种设备的控制通常是独立分开**

  Often independently controlled

  –放置地点太接近、传感器校正不准确，会造成这二个设备相互干扰

  Tight ranges and poor sensor calibration lead to units fighting

机房空调单元可阻挡外部热气进入
CRAC Units Reject Heat Outside

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

干式冷却器DX (Dry-Cooler DX)

气冷式DX (Air-Cooled DX)

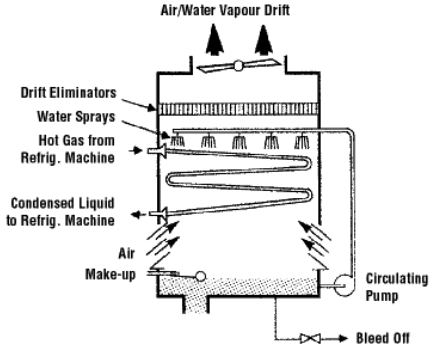
乙二醇 Glycol

冷冻剂 Refrigerant

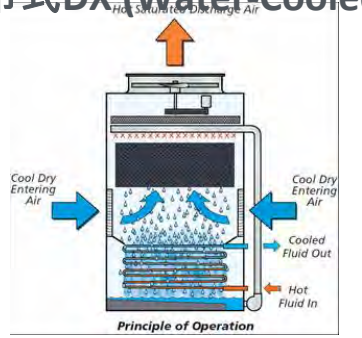
冷冻剂 Refrigerant

水 Water

蒸发冷却DX (Evaporatively-Cooled DX)



水冷式DX (Water-Cooled DX)



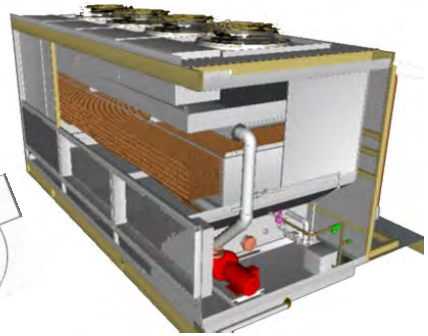
空气处理单元使用冷却水
CRAH Units Use Chilled-Water

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

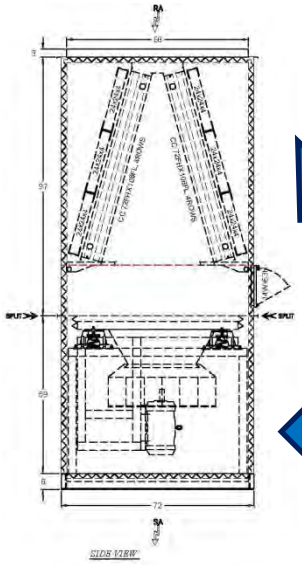
气冷式冷却器 Air-Cooled Chiller

冷却塔 Cooling Tower

蒸发冷却式冷却器 Evap-Cooled Chiller



空气处理单元 CRAH



水 Water

水 Water

水 Water

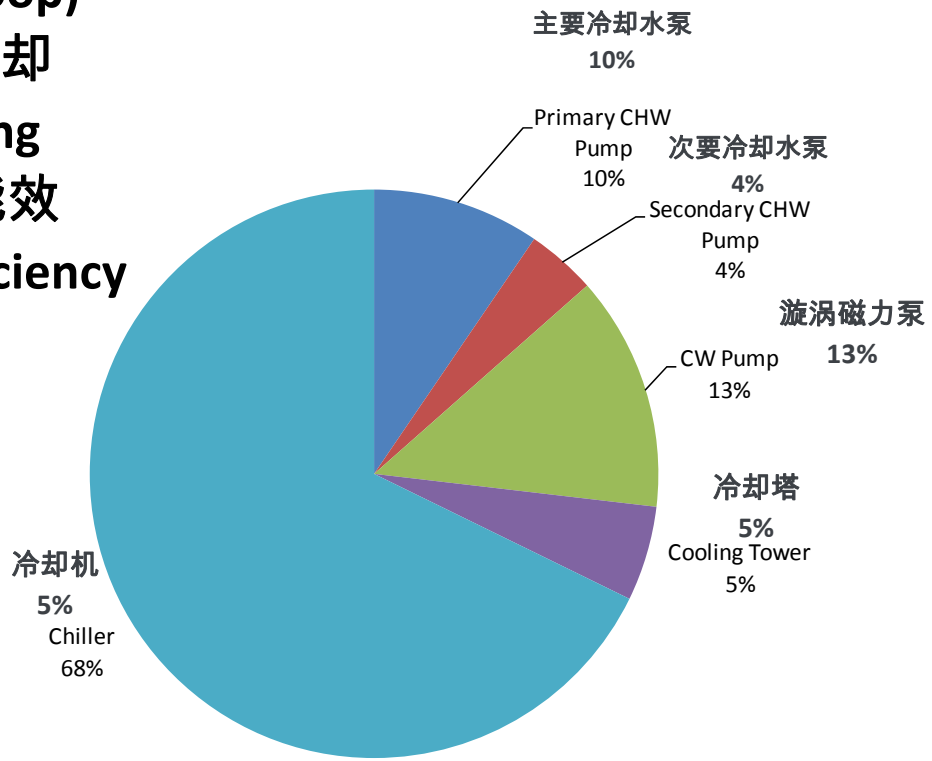
水 Water

水冷式冷却器 Water-Cooled Chiller

优化冷却厂
Optimize the Chiller Plant

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

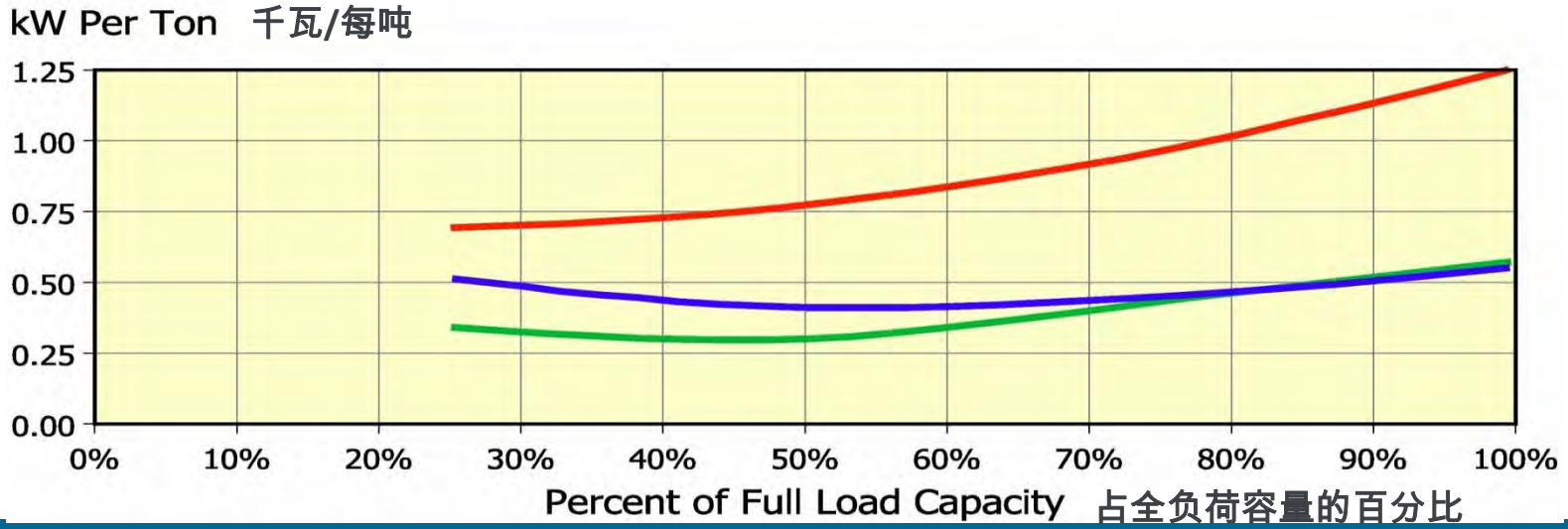
- 设立一个专门的工厂 (相对于使用分布式冷却)
  Have a plant (vs. distributed cooling)
- 使用“温水”制冷(多循环)
  Use “warm” water cooling (multi-loop)
- 冷却塔大小适中，可实现“免费”冷却
  Size cooling towers for “free” cooling
- 整合所有主要元件的控制与监测能效
  Integrate controls and monitor efficiency of all primary components
- 热储存
  Thermal storage
- 在以下设备安装可调速驱动器
  Utilize variable speed drives on:
  - 风机、泵、塔、冷却器
    Fans, pumps, towers, chillers



选择高能效冷却机
Select Efficient Chillers

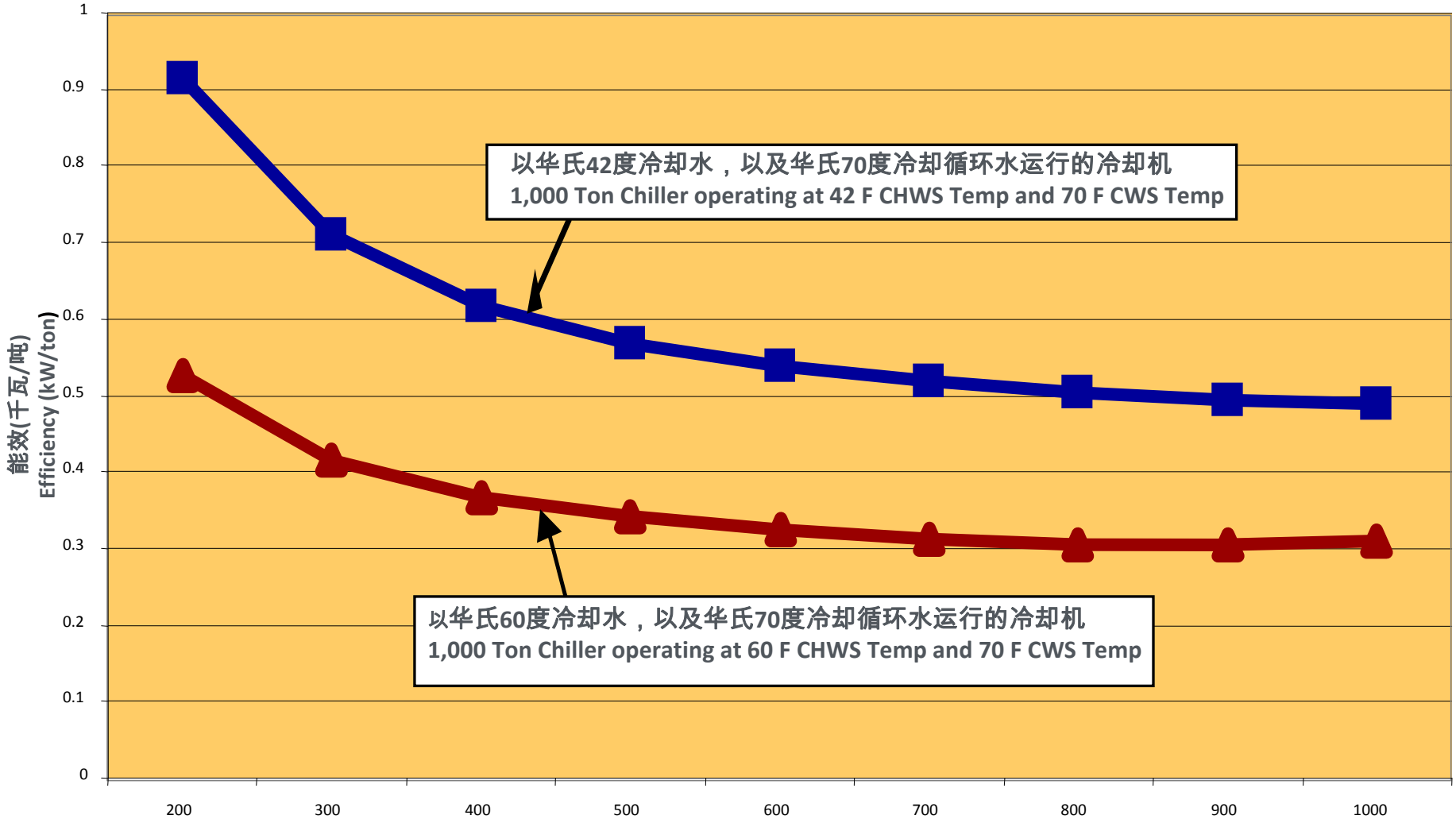
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

冷却器 Chiller	压缩机 (千瓦/吨) Compressor (kW / ton)			
	25%	50%	75%	100%
400吨气冷式冷却机 400 Ton Air Cooled	0.69	0.77	0.96	1.25
1200吨水冷式冷却机(无 可调速驱动器) 1200 Ton Water Cooled w/o VFD	0.51	0.41	0.45	0.55
1200吨水冷式冷却器(有可调速驱动器) 1200 Ton Water Cooled with a VFD	0.34	0.30	0.43	0.57



提高冷却机的温度
Increase Temperature of Chiller

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



数据来源：约克国际公司
Data provided by York International Corporation.

新兴技术：液体冷却
Emerging Technology: Liquid Cooling

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

随着热密度的增加，液体冷却方法(再次)受到瞩目

As heat densities rise, liquid solutions become more attractive (again):

容积热容量比较

Volumetric heat capacity comparison

400加仑水池

水 Water

=

空气 Air

为何选择液体冷却?
Why Liquid Cooling?

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 液体越靠近热源，除热效率越高

  Heat removal efficiency increases as liquid gets closer to the heat source

- 液体也用于冷却

  Liquids can provide cooling with higher temperature coolant

  - 提高冷却效率

    Improved cooling efficiency

  - 延长节能装置的使用寿命

    Increased economizer hours

  - 扩大余热的用途

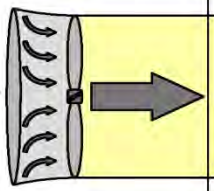
    Greater potential use of waste heat

为何选择液体冷却?
Why Liquid Cooling?

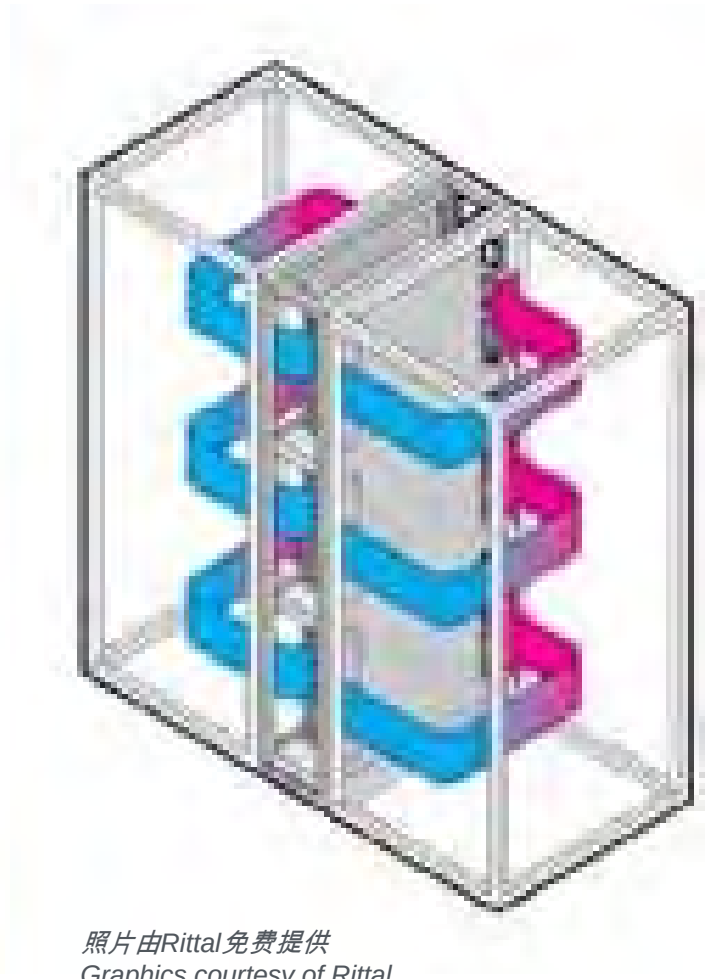
- 减少运输能耗

Reduced transport energy:

热传递 由此产生的能源需求

Heat Transfer		Resultant Energy Requirements			
Rate 速度	ΔT	Heat Transfer Medium 热传递介质	Fluid Flow Rate 液体流速	Conduit Size 导管直径	Theoretical Horsepower 理论上的马力
10 Tons 10吨	12°F	Forced Air 加压气流 	9217 cfm	34" Ø	3.63 Hp
		Water 水 	20 gpm	2" Ø	.25 Hp

In-row通道配线间液体冷却
In-row Liquid Cooling

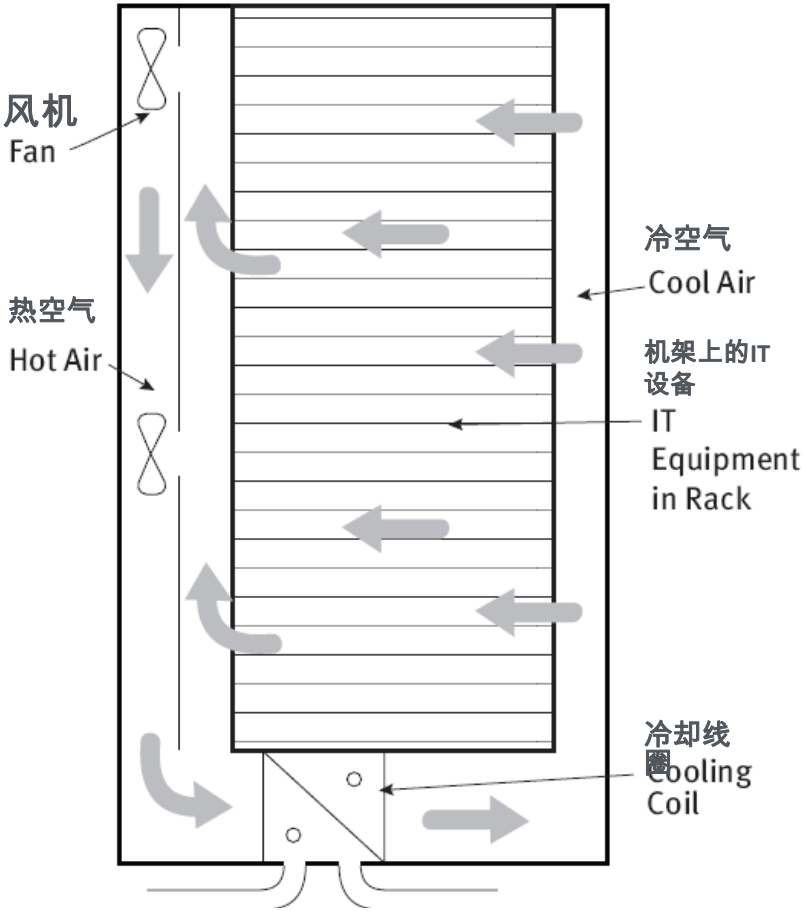


照片由Rittal免费提供
Graphics courtesy of Rittal

机架液体冷却
In-rack liquid cooling

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

整合所有线圈并完全包覆的机架
Racks with integral coils and full containment



后门液体冷却
Rear-Door Liquid Cooling

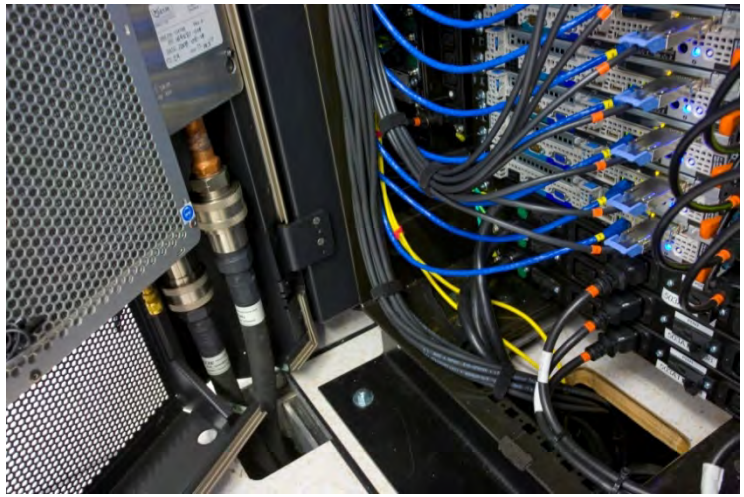
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

后门(开启状态)
Rear Door (open)

内部机架RD Hx，90度开启
Inside rack RDHx, open 90°

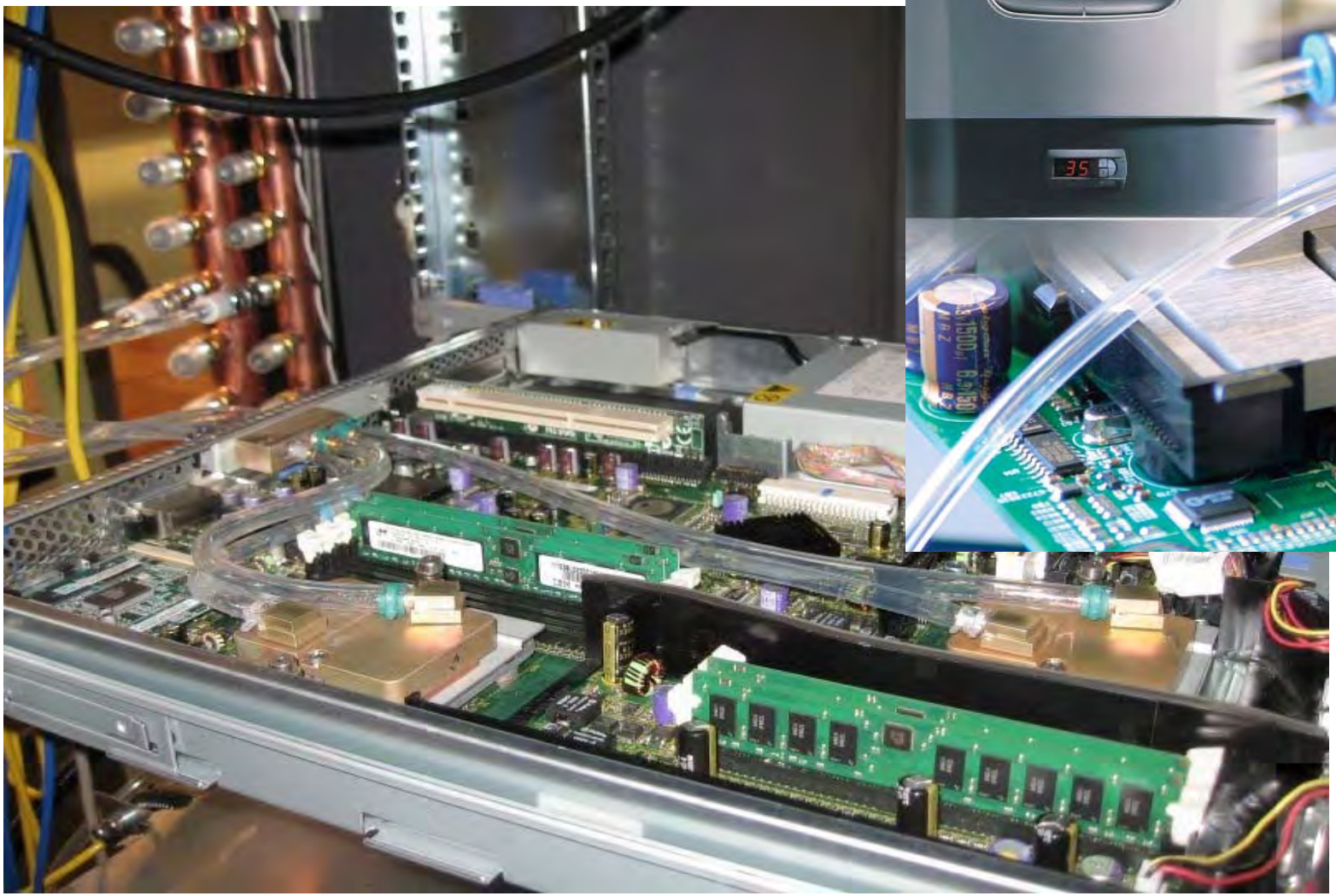
后门(关闭状态)
Rear Doors (closed)

液体冷却连接管道Liquid Cooling Connections



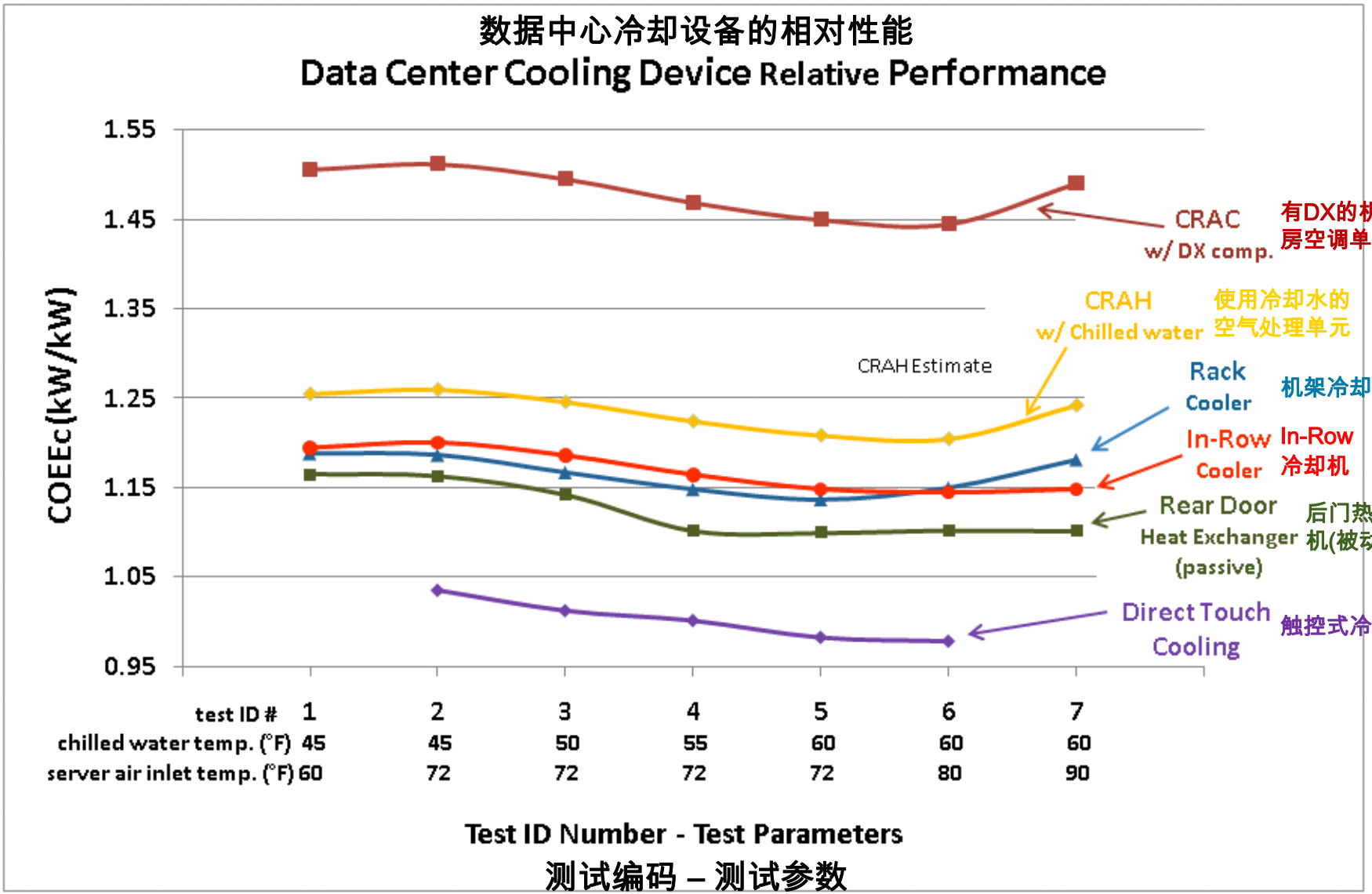
板上液体冷却
On Board Liquid Cooling

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



“第二回冷却”评估
“Chill-off 2” evaluation

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



采用免费冷却：
Use Free Cooling:

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

不用压缩机的制冷
Cooling without Compressors:

- 外部空气节能器
  Outside-Air Economizers
- 水侧节能器
  Water-side Economizers

➢ 咱们拆掉数据中心的冷却器吧
Let's get rid of chillers in data centers

冷却的平均能耗 (Avg. Power for Cooling)			
暖通空调制冷	23%	(HVAC Cooling	23%)
暖通空调风机	8%	(HVAC Fans	8%)
总计	31%	(TOTAL	31%)
全部使用节能器		(Using 100% Economizer)	

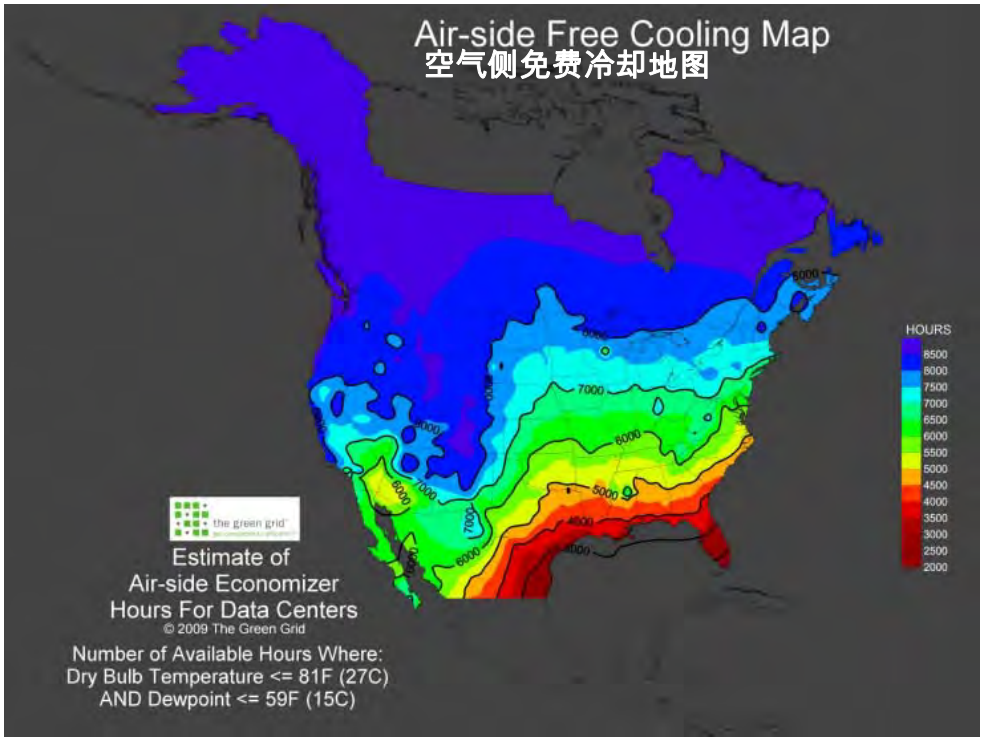
节能量：23 / 31=74% (Energy Savings = 23 / 31= 74%)

外部空气节能器
Outside-Air Economizers

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

优点
Advantages

- 能耗低
  Lower energy use
- 稳定度高(制冷系统的备用机)
  Added reliability (backup for cooling system)



http://cooling.thegreengrid.org/namerica/WEB_APP/calc_index.html

外部空气节能器
Outside-Air Economizers

潜在问题 Potential Issues

- 安装空间
  Installation space.
- 灰尘
  Dust
  - 如有13个Merv 除尘器，问题就不大
    Not a concern with Merv 13 filters
- 气态污染物
  Gaseous contaminants
  - 范围不大
    Not widespread
  - 通常会影响已经过制冷的数据中心
    Impacts normally cooled data centers as well
- 烟雾如出现在数据中心外面，只要关闭或不接触到即可
  Shutdown or bypass if smoke is outside data center.

加州大学的CRT设施
UC's CRT Facility

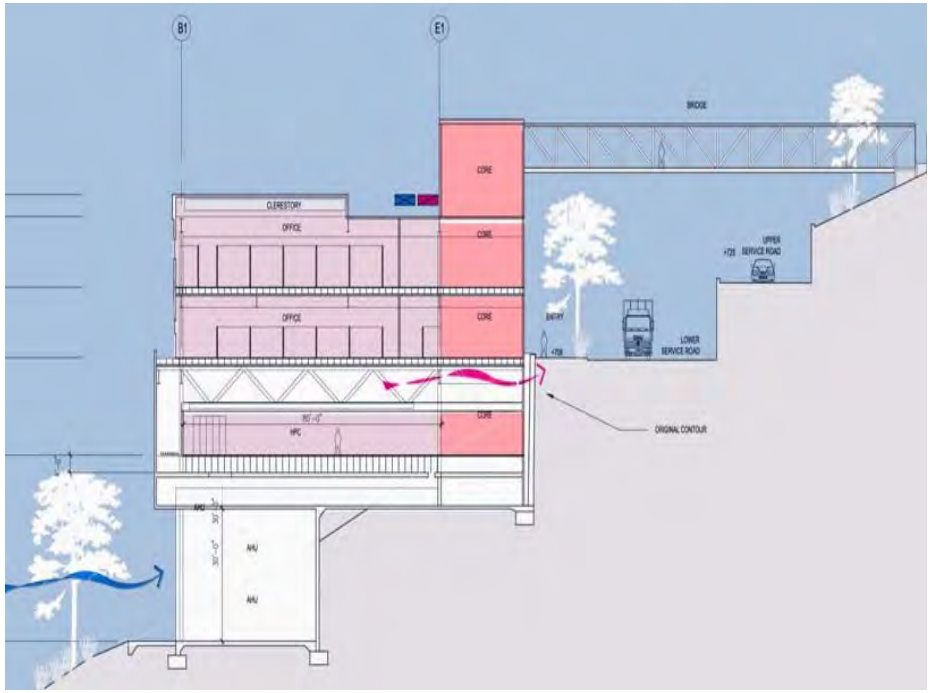
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

系统设计方法
System Design Approach:

- 免费制冷
  Free cooling
- 空气侧节能器(运行时间的93%)
  Air-side economizer(93% of hours)
  - 用于加湿与预先制冷的直接蒸发制冷
    Direct evaporative cooling for humidification and pre-cooling

系统设计方法
System Design Approach:

- 以下设备也有液体制冷功能
  Liquid cooling also available
  - 冷却塔规模的节能器
    Tower side economizer
  - 四管式系统
    Four pipe system
- 重复使用余热
  Waste heat reuse
- 年电源利用效率 PUE=1.1(预估)
  Annual PUE = 1.1(predicted)

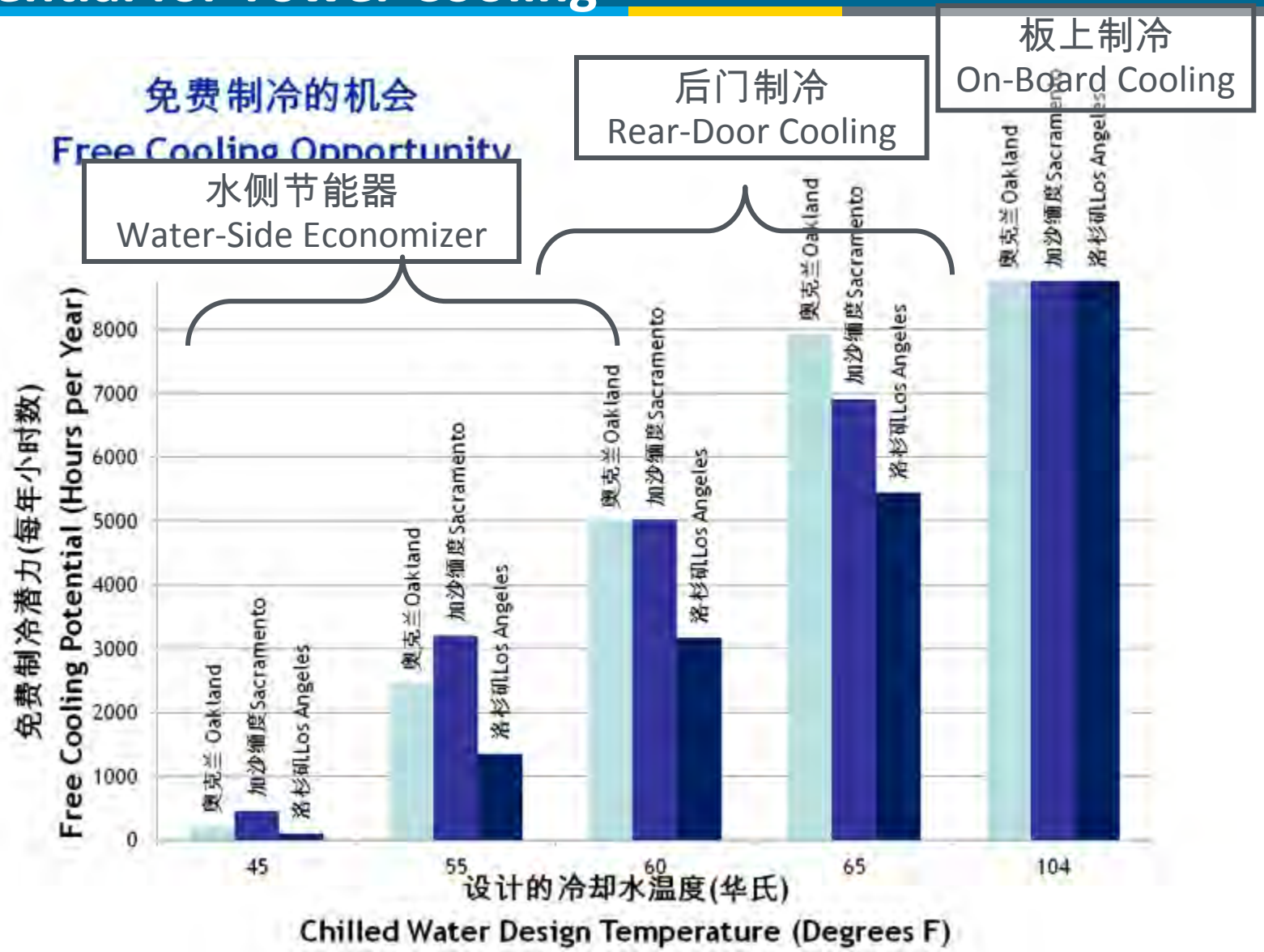


水侧节能器
Water-Side Economizers

优点
Advantages

- 在干冷气候下使用很划算
  Cost effective in cool and dry climates
- 通常改造比较容易
  Often easier retrofit
- 稳定度提高(万一冷却机故障时可作为备用)
  Added reliability (backup in the event of chiller failure)
- 无污染问题
  No contamination questions

塔式冷却的潜力
Potential for Tower Cooling



LBNL 实例：后门制冷
LBNL Example: Rear Door Cooling

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 取代机房空调单元

  Used instead of adding CRAC units
- 仅限塔式的后门水制冷 (或接连使用中央冷却厂)

  Rear door water cooling with tower-only (or central chiller plant in series).

改进对湿度的控制:
Improve Humidity Control:

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 消除偶然的除湿
  Eliminate inadvertent dehumidification
  - 计算机负荷是敏感的
    Computer load is sensible only
- 使用美国采暖制冷与空调工程师学会推荐的湿温相对度(RH)和温度
  Use ASHRAE allowable ranges
  - 许多制造商允许更大的湿度范围
    Many manufacturers allow even wider humidity range
- 消除设备的不协调性
  Eliminate equipment fighting
  - 协调控制
    Coordinate controls
  - 停用一台机房空调单元/空气控制单元，或只控制补给空气的湿度
    Disconnect and only control humidity of makeup air or one CRAC/CRAH unit
  - 全部停用(很多地方已这么做!)
    Entirely disconnect (many have!)

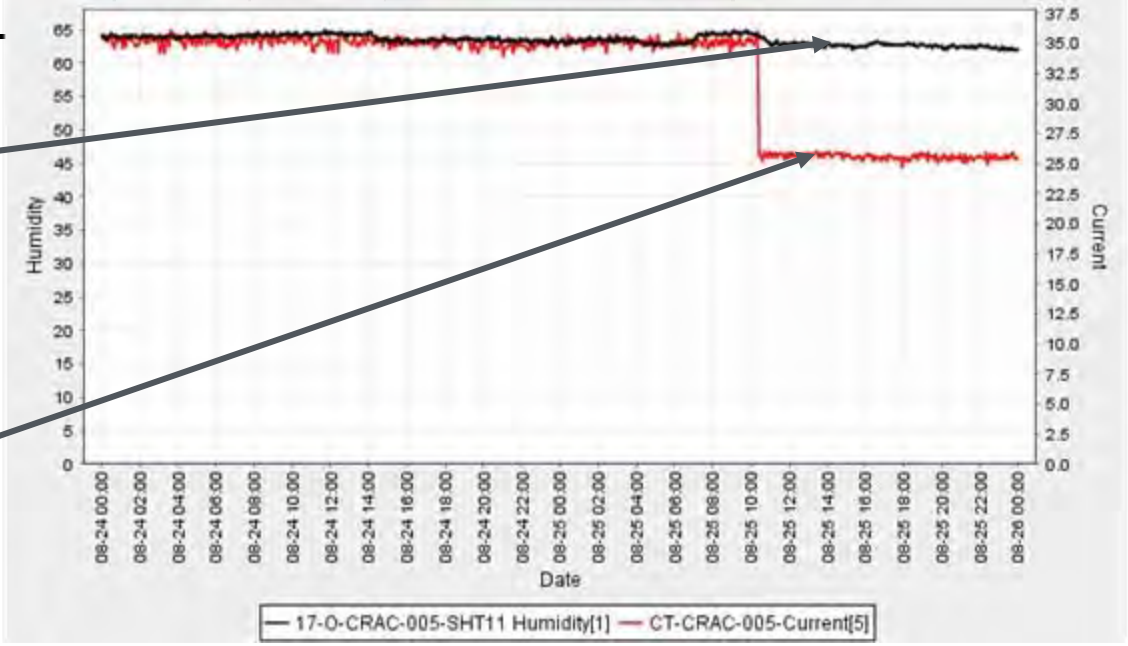
不必要的湿度所带来的成本
The Cost of Unnecessary Humidification

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

	Visalia Probe			CRAC Unit Panel 机房空调单元面板			
	Temp	RH	Tdp	Temp	RH	Tdp	Mode
AC 005	84.0	27.5	47.0	76	32.0	44.1	Cooling 制冷
AC 006	81.8	28.5	46.1	55	51.0	37.2	Cooling & Dehumidification 制冷&除湿
AC 007	72.8	38.5	46.1	70	47.0	48.9	Cooling 制冷
AC 008	80.0	31.5	47.2	74	43.0	50.2	Cooling & Humidification 制冷&除湿
AC 010	77.5	32.8	46.1	68	45.0	45.9	Cooling 制冷
AC 011	78.9	31.4	46.1	70	43.0	46.6	Cooling & Humidification 制冷&除湿
Min	72.8	27.5	46.1	55.0	32.0	37.2	
Max	84.0	38.5	47.2	76.0	51.0	50.2	
Avg	79.2	31.7	46.4				

湿度下降3%
Humidity down 3%

机房空调电耗下降28%
CRAC power down 28%



制冷重点回顾
Cooling Takeaways…

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 采用中央工厂(如制冷机/空气处理单元)vs.机房空调单元

  Use a central plant (e.g. chiller/CRAHs) vs. CRAC units
- 机房空调单元/空气处理单元采用中央控制方法

  Use centralized controls on CRAC/CRAH units
  - 避免同时进行加湿与除湿

    Prevent simultaneous humidifying and dehumidifying
  - 优化工作的排序与进行

    Optimize sequence and staging
- 改用液体制冷(房间、排、机架、晶片)

  Move to liquid cooling (room, row, rack, chip)

制冷重点回顾
Cooling Takeaways…

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 考虑在风机、泵、冷水机组与冷却塔安装可调速驱动器

  Consider VSDs on fans, pumps, chillers, and towers
- 尽可能使用空气侧或水侧节能装置

  Use air- or water-side economizers where possible.
- 提高湿度范围并改善对湿度的控制(或中断)

  Expand humidity range and improve humidity control (or disconnect).

Questions? 问题？

报告提纲
AGENDA

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 介绍课程内容和课程讲师
- 数据中心绩效指标和对标
- IT设备和软件效率
- 利用IT节约IT（监测和展示盘）
- 数据中心环境条件
- 气流管理
- 制冷系统
- **电气系统**
- **参考资料和研讨会总结**

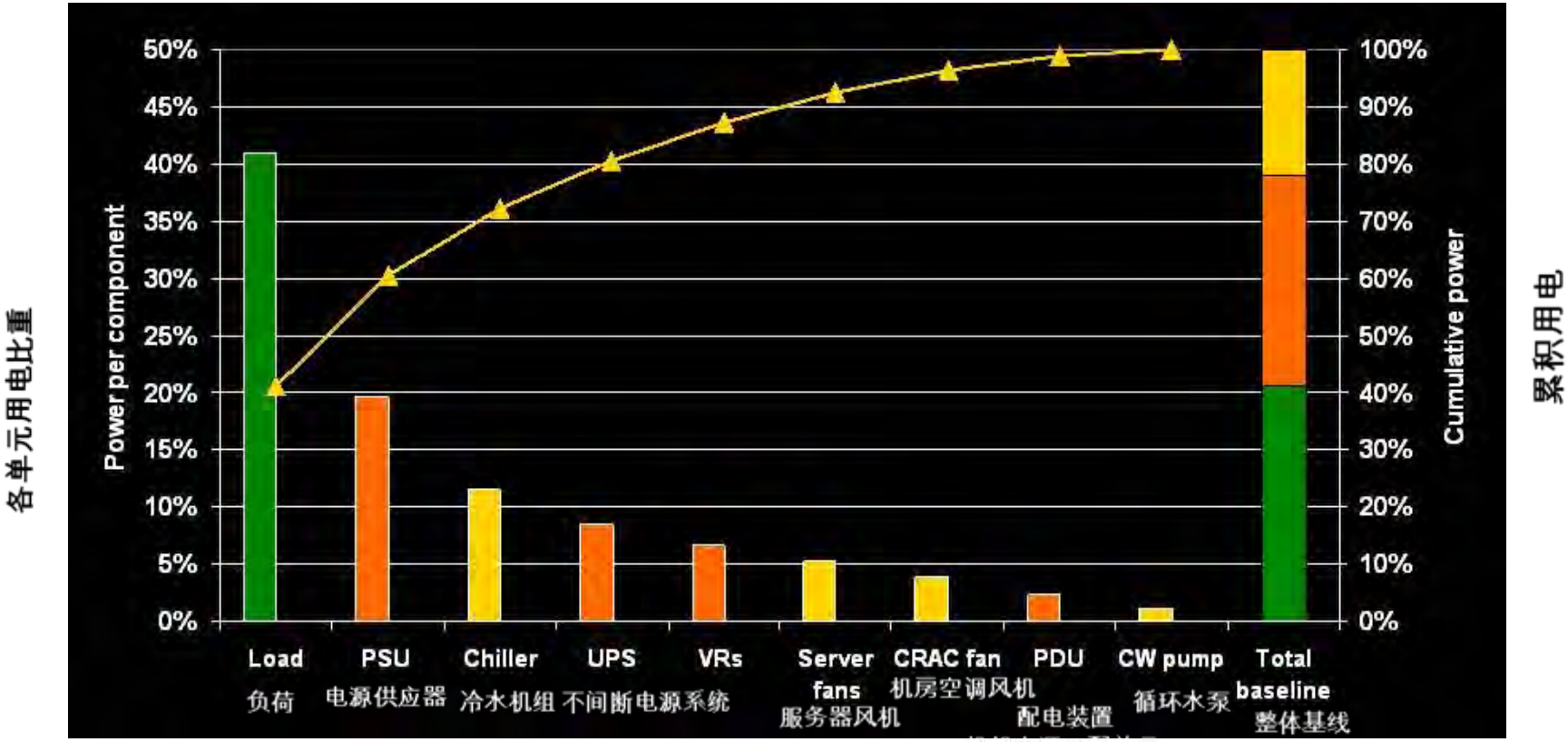
- Introductions to course and instructors
- Performance metrics and benchmarking
- IT equipment and software efficiency
- Use IT to save IT (monitoring and dashboards)
- Data center environmental conditions
- Airflow management
- Cooling systems
- **Electrical systems**
- **Resources and Workshop Summary**

电气系统

Electrical Systems

电气系统的终端使用 –橘色柱状区域
Electrical system end use – Orange bars

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



本图由英特尔公司的Michael Patterson免费提供
Courtesy of Michael Patterson, Intel Corporation

电力配送
Electrical Distribution

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 电力转换时，均会出现能耗损失与发热的情形

  Every power conversion (AC-DC, DC-AC, AC-AC) loses some energy and creates heat

- 负荷很少时，会降低系统的效率

  Efficiency decreases when systems are lightly loaded
  - 冗余负荷不应该超过规定的范围(N+1与2N有很大的区别)
    Redundancy should be used only to the required level (N+1 is much different than 2N)

电力配送
Electrical Distribution

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 高压配电的能效较高，成本也较低(导体体积较小)

  Distributing higher voltage is more efficient and saves capital cost (conductor size is smaller)
- 供电、不间断供电(UPS)、变压器与机架电源分配单元(PDU)的能效各有不同 –要谨慎选择

  Power supplies, Uninterruptible power supply (UPS), transformer, and PDU efficiencies vary – carefully select
- 减少配电过程的能量损失，也能减少制冷所需的用电负荷

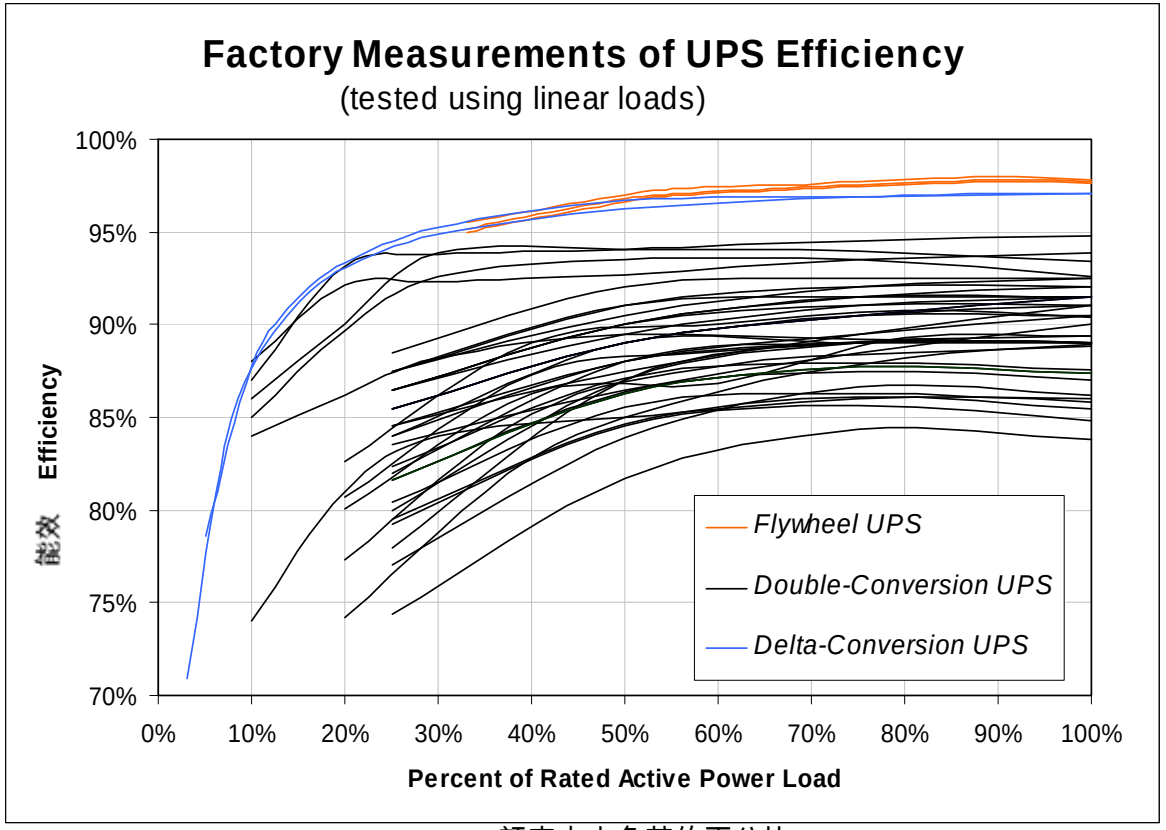
  Lowering distribution losses also lowers cooling loads

不间断电原系统、变压器、机架电源分配单元的能效
UPS, transformer, & PDU efficiency

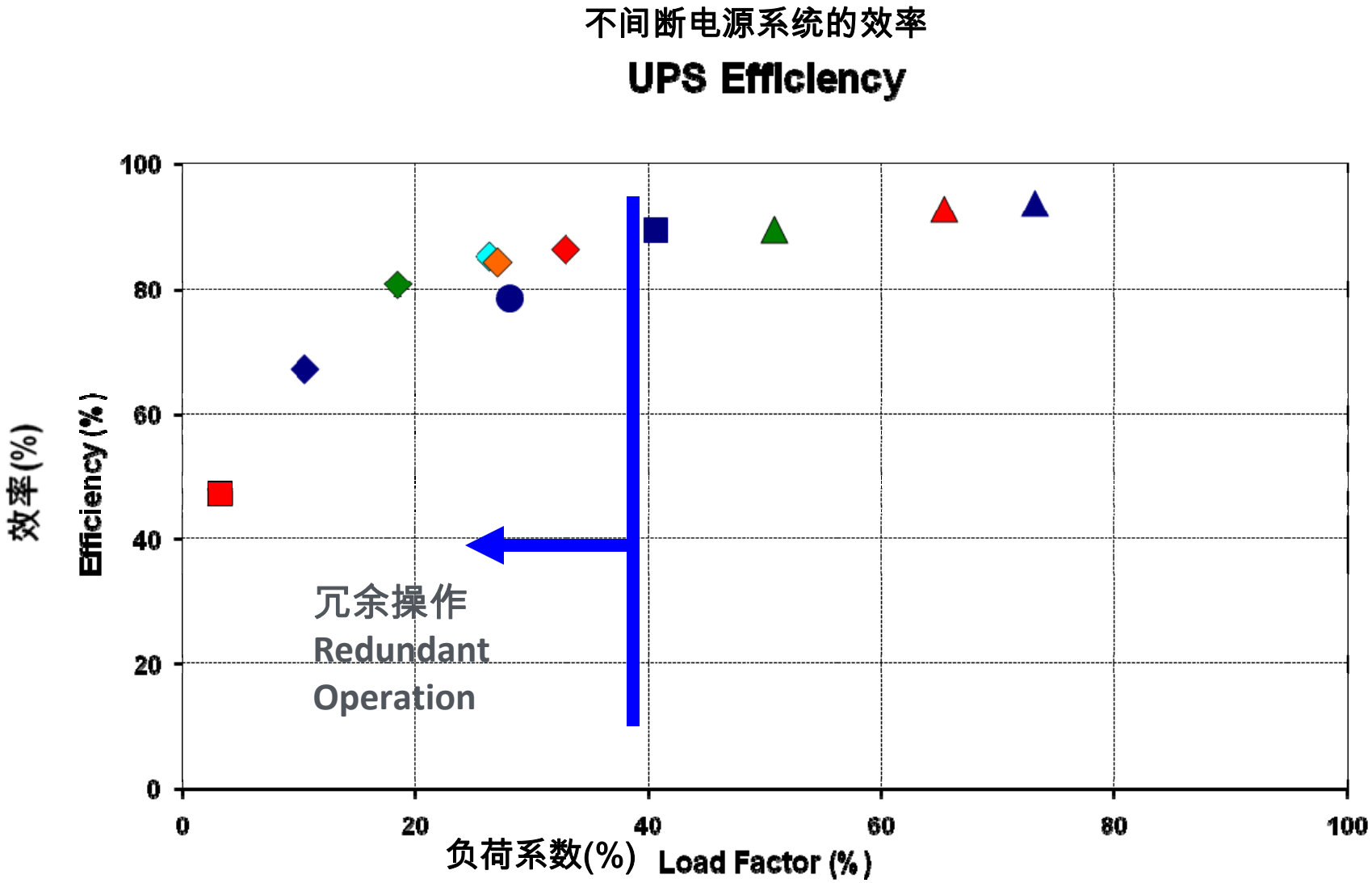
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 能效会因系统设计、设备与负荷的不同，而出现差异
  Efficiencies vary with system design, equipment, and load
- 冗余负荷会影响能效
  Redundancies impact efficiency

不间断电原系统效率的因素测量
(线性负荷测试)



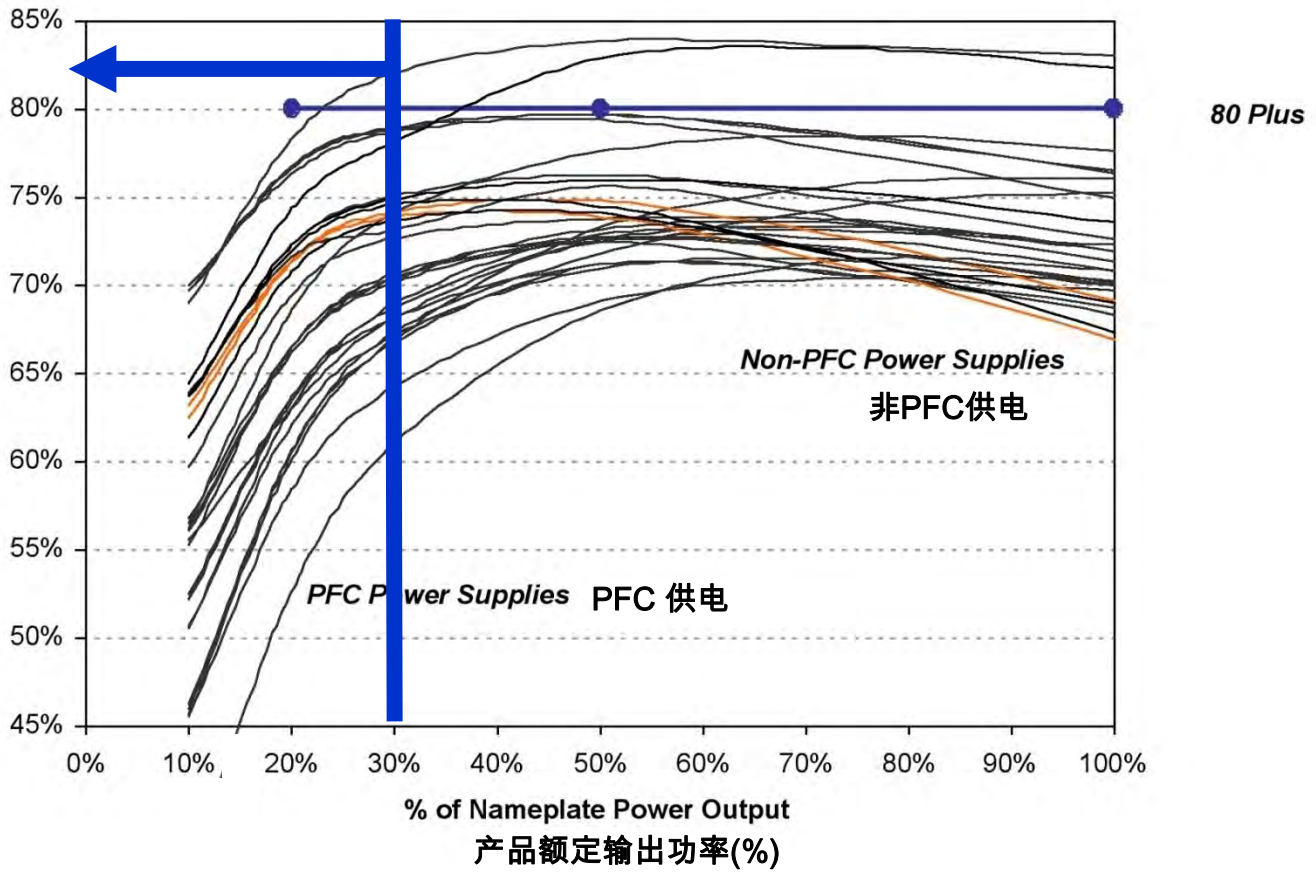
测量到的不间断电源系统的效率
Measured UPS efficiency



LBNL/电力研究所（EPRI）测量到的电源供应效率
LBNL/EPRI Measured Power Supply Efficiency

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

测量到的服务器电源供应效率 (所有的因素)
Measured Server Power Supply Efficiencies (all form factors)



冗余
Redundancy

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 了解什么是冗余成本——是否值得？

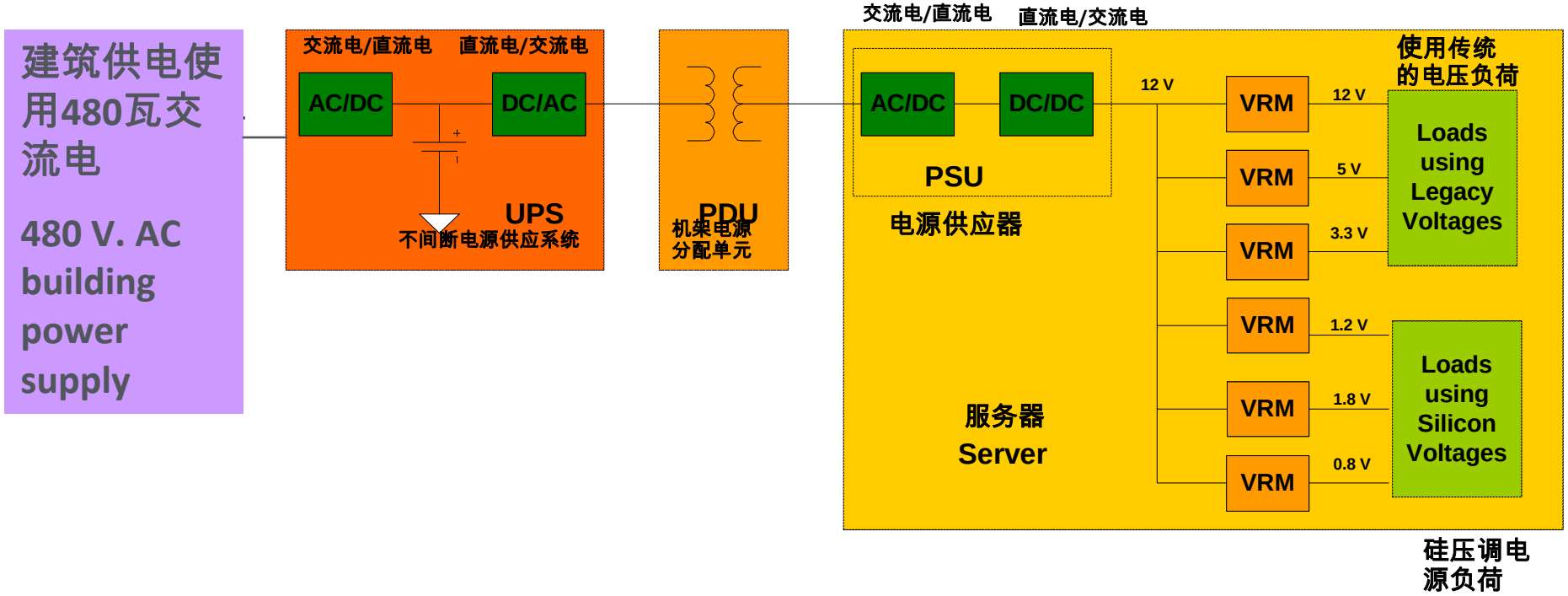
  Understand what redundancy costs – is it worth it?
- 各种操作是否都要相同的电功率?

  Does everything need the same level of?
- 不同的策略会带来不同的能效损失（如，2N vs. N+1)

  Different strategies have different energy penalties（e.g. 2N vs. N+1)
- 电力分配中的冗余将降低能效

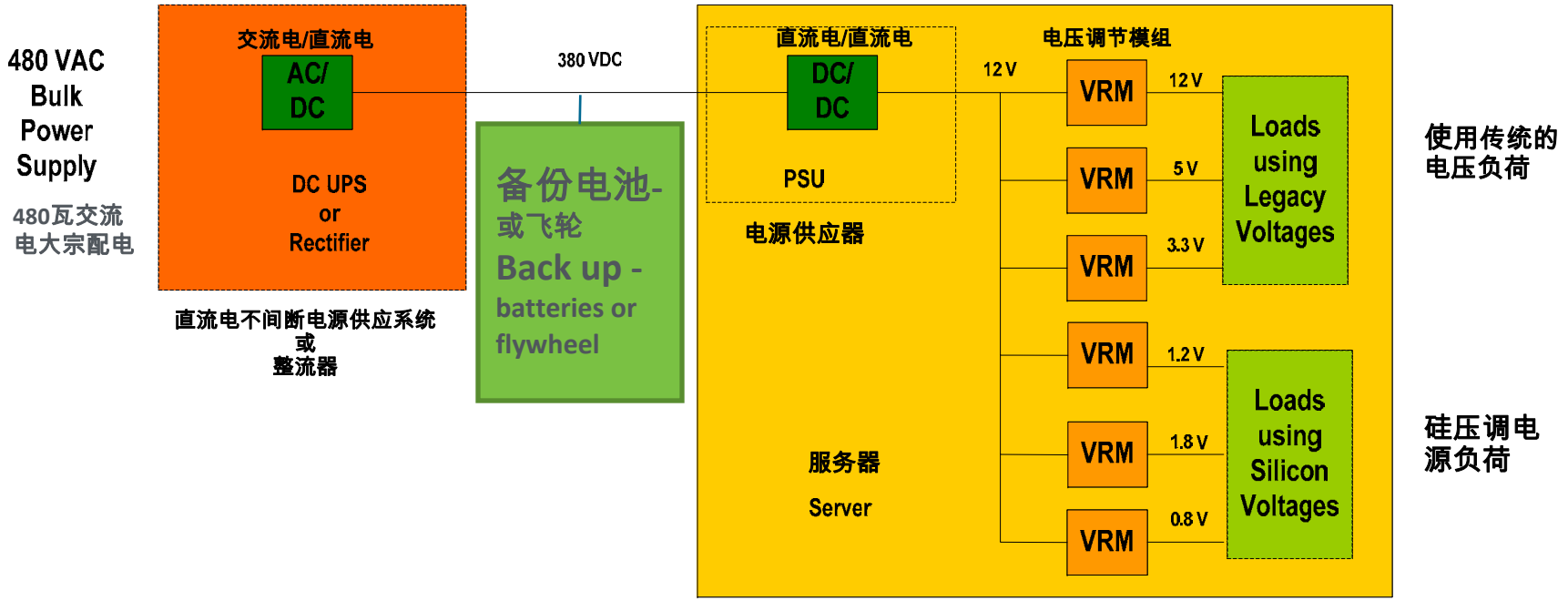
  Redundancy in electrical distribution puts you down the efficiency curve

“当今”的交流电配送….
“Today’s” AC distribution…



380瓦直流电配电
380V. DC power distribution

- 使用直流电可避免多次的电力转换
  DC power can eliminate several stages of conversion
- 也是用于照明、可调速驱动器以及现场发电
  Also use for lighting, variable speed drives, and , and on-site generation



电力供应系统重点回顾
Key Electrical Takeaways

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 选择高能效的单元与设定
  Choose highly efficient components and configurations
- 减少电力转换次数(交流电-直流电、直流电-交流电、交流电-交流电、直流电-直流电)
  Reduce power conversion (AC-DC, DC-AC, AC-AC, DC-DC)
- 考虑使用最低限度的冗余负荷，因为系统负荷太少时，效率会降低
  Consider the minimum redundancy required as efficiency decreases when systems are lightly loaded
- 使用高压电
  Use higher voltage
- 直流电系统会减少转换时的能量损耗
  Direct Current (DC) systems can reduce conversion losses.

Questions? 问题？

报告提纲 AGENDA

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 介绍课程内容和课程讲师
- 数据中心绩效指标和对标
- IT设备和软件效率
- 利用IT节约IT（监测和展示盘）
- 数据中心环境条件
- 气流管理
- 制冷系统
- 电气系统
- **参考资料和研讨会总结**

- Introductions to course and instructors
- Performance metrics and benchmarking
- IT equipment and software efficiency
- Use IT to save IT (monitoring and dashboards)
- Data center environmental conditions
- Airflow management
- Cooling systems
- Electrical systems
- **Resources and Workshop Summary**

参考资料和研讨会总结

Resources and Workshop Summary

美国方面的项目和资源介绍
US Programs/Resources

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

先进制造办公室 (Advanced Manufacturing Office)

- 建立基线使用的套装工具与标准
  Tool suite & metrics for baselining
- 培训合格的专业人员
  Training Qualified specialists
- 案例研究
  Case studies
- 标彰节能高度有成的机构
  Recognition of high energy savers
- 研发- 技术开发
  R&D - technology development

Save ENERGY Now

联邦能源管理项目
(Federal Energy Management Program)

- 研讨会(Workshops)
- 联邦案例研究(Federal case studies)
- 帮政策指引(Federal policy guidance)
- 信息交换与推广(Information exchange & outreach)
- 提供融资机会(Access to financing opportunities)
- 技术援助(Technical assistance)

FEMP

总务局(GSA)

- 研讨会 (Workshops)
- 快速使用节能指南
  (Quick Start Efficiency Guide
- 技术支援 (Technical Assistance)

GSA

环保署 (EPA)

- 衡量标准 (Metrics)
- 服务器性能评分&能源之星标识
  (Server performance rating & ENERGY STAR label)
- 数据中心对标 (Data center benchmarking)

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

energy ENERGY STAR

工业(Industry)

- 工具（Tools）
- 衡量标准（Metrics）
- 培训（Training）
- 最佳实践信息
  （Best practice information）
- 卓越典范指南（Best-in-Class guidelines）
- IT工作生产力标准(IT work productivity standard)

INFORMATION TECHNOLOGY INDUSTRY COUNCIL

Uptime Institute

Silicon Valley Leadership Group

7X24 Exchange

ASHRAE

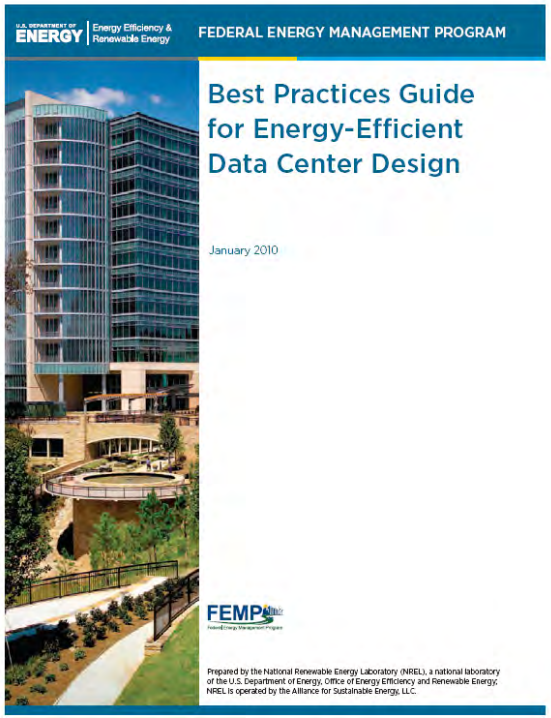
AFCOM

Critical Facilities ROUNDTABLE

联邦层面的数据中心信息资源
Federal Data Center Resources

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- 最佳实践指南
  Best Practices Guide
- 对标指南
  Benchmarking Guide
- 数据中心编程指南
  Data Center Programming Guide
- 技术案例研究辑录
  Technology Case Study Bulletins
- 采购规范
  Procurement Specifications
- 报告模板
  Report Templates
- 工艺流程手册
  Process Manuals
- 快速使用指南
  Quick-Start Guide



美国能源部的先进制造办公室(过去名为“工业技术项目”)的数据中心项目提供多种工具与信息资源，可协助企业主与营运单位：

DOE’s AMO (was ITP) data center program provides tools and resources to help owners and operators:

- **DC Pro 软件工具包**
  DC Pro Software Tool Suite
  - 用于划定能耗基线并发掘节能机会
    Tools to define baseline energy use and identify energy-saving opportunities

- **信息产品**
  Information products
  - 有助于找出并减少运行成本，同时重建数据中心基础建设能力的手册、案例研究与其他资源
    Manuals, case studies, and other resources to identify and reduce operating costs, and regain data center infrastructure capacity

- **对终端用户提供培训，提高节能意识**

  End-user awareness training

  - 结合ASHRAE的研讨会

    Workshops in conjunction with ASHRAE

- **数据中心节能实践者(DCEP)认证项目**

  Data Center Energy Practitioner (DCEP) certificate program

  - 评估节能机会的专业人士认证

    Qualification of professionals to evaluate energy efficiency opportunities

- **对先进技术进行研发与示范**

  Research, development, and demonstration of advanced technologies

美国能源部DC Pro 软件工具包
DOE DC Pro Tool Suite

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

高级在线分析与跟踪工具
High-Level On-Line Profiling and Tracking Tool

- 整体能效(电力运用利用率[PUE])
  Overall efficiency (Power Usage Effectiveness [PUE])
- 终端使用方面的突破
  End-use breakout
- 有可能提高能效的几个方面
  Potential areas for energy efficiency improvement
- 整体的节能潜力
  Overall energy reduction potential

深度分析工具→ 节能量
In-Depth Assessment Tools → Savings

空气管理 Air Management	电力系统 Electrical Systems	IT设备 IT-Equipment	制冷 Cooling

什么是“能源之星”?
What is ENERGY STAR?

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

一项由政府及民间单位共同合作的项目

A voluntary public-private partnership program

- 建筑

  Buildings
- 产品

  Products

信息资源
Resources

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

FEMP Federal Energy Management Program

http://www1.eere.energy.gov/femp/program/data_center.html

BERKELEY LAB

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

ENERGY STAR

http://www.energystar.gov/index.cfm?c=prod_development.server_efficiency

Save ENERGY Now ®

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

数据中心最佳实践摘要
Data Center Best Practices Summary

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

1. 能耗测量和对标
   Measure and Benchmark Energy Use
2. 找出IT节能机会
   Identify IT Opportunities
3. 通过IT来控制IT设备的能耗
   Use IT to Control IT
4. 管理气流
   Manage Airflow
5. 优化环境条件
   Optimize Environmental Conditions
6. 评估制冷方法
   Evaluate Cooling Options
7. 提高电力能效
   Improve Electrical Efficiency
8. 实施节能措施
   Implement Energy Efficiency Measures

1. 能耗测量和对标

Measure and Benchmark Energy Use

- 使用多项指标来测量能效

  Use metrics to measure efficiency
- 将能效表现进行对标

  Benchmark performance
- 建立持续改进目标

  Establish continual improvement goals

2. 找出IT节能机会

Identify IT Opportunities

- 具体说明高能效服务器的规格(含电源供应)

  Specify efficient servers (incl. power supplies)
- 虚拟化

  Virtualize
- 更新IT设备并淘汰没有采用的设备

  Refresh IT equipment, and decommission unused equipment.

3. 使用IT来控制IT设备的能耗

Use IT to Control IT Energy

- 评估监测系统的表现，以强化实时管理并提高能效

  Evaluate monitoring systems to enhance real-time management and efficiency.

- 使用虚拟化工具(如，热力图)

  Use visualization tools (e.g. thermal maps).

- 使用展示盘以管理能效及保持节能效果

  Install dashboards to manage and sustain energy efficiency.

4. 管理气流

Manage Airflow

- 采行热通道与冷通道

  Implement hot and cold aisles
- 修补泄漏

  Fix leaks
- 管理地砖

  Manage floor tiles
- 分离冷热气流

  Isolate hot and cold airstreams

5. 优化环境条件

Optimize Environmental Conditions

- 采用ASHRAE指南或制造商提供的规格要求

  Follow ASHRAE guidelines or manufacturer specifications
- 运行时，采用ASHRAE建议值上限

  Operate to maximum ASHRAE recommended range.
- 预期服务器偶尔会在可容许的现值内运行

  Anticipate servers to occasionally operate in allowable range.
- 减少或完全不用湿度控制

  Minimize or eliminate humidity control

6. 评估制冷的几种方法

Evaluate Cooling Options

- 使用中央制冷系统

  Use centralized cooling system
- 提高中央制冷工厂的能效

  Maximize central cooling plant efficiency
- 提供液体除热的方法

  Provide liquid-based heat removal
- 无需压缩机的制冷法

  Compressorless cooling

7. 提高电力效率

Improve Electrical Efficiency

- 选择高效的不间断电源供应系统与剖析图
  Select efficient UPS systems and topography
- 检查冗余的程度
  Examine redundancy levels
- 增加高压配电并减少电力转换次数
  Increase voltage distribution and reduce conversions

8. 实施标准的节能措施

Implement Standard Energy Efficiency Measures

- 安装最好的高效电机

  Install premium efficiency motors
- 更新建筑能效自动化控制系统

  Upgrade building automation control system
  - 整合机房空调单元的控制功能

    Integrate CRAC controls
- 一切采用变速驱动装置

  Variable speed everywhere
- 优化冷却塔的能效

  Optimize cooling tower efficiency

更重要的是…

Most importantly…

数据中心的IT和设施管理人员沟通与合作!!!

Get IT and Facilities People Talking and working together as a team!!!

联系方式
Contact Information:

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

夏明德，注册工程师 Dale Sartor, P.E.
应用工程小组 Applications Team
加州伯克利，劳伦斯伯克利国家实验室
Lawrence Berkeley National Laboratory
MS 90-3111
University of California
Berkeley, CA 94720
DASartor@LBL.gov
(510) 486-5988
http://Ateam.LBL.gov

BERKELEY LAB