

# Benchmarking:

## What's Your Building's Energy IQ?

Evan Mills, Ph.D.

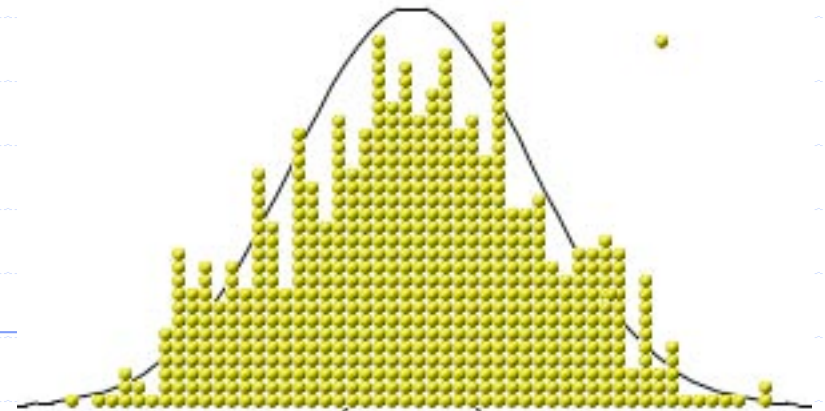
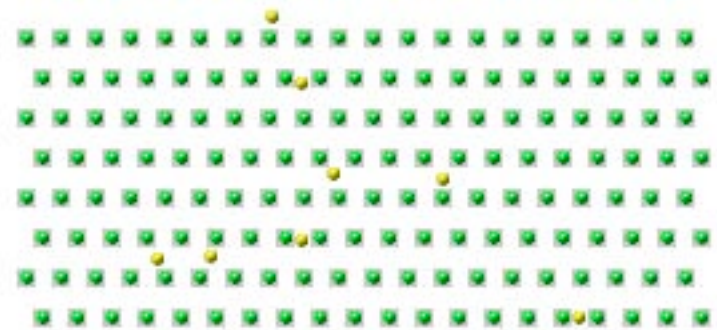
Lawrence Berkeley  
National Laboratory

EMills@lbl.gov

*California Energy Commission*

**Green Building Initiative Benchmarking Staff Workshop**

April 7, 2005

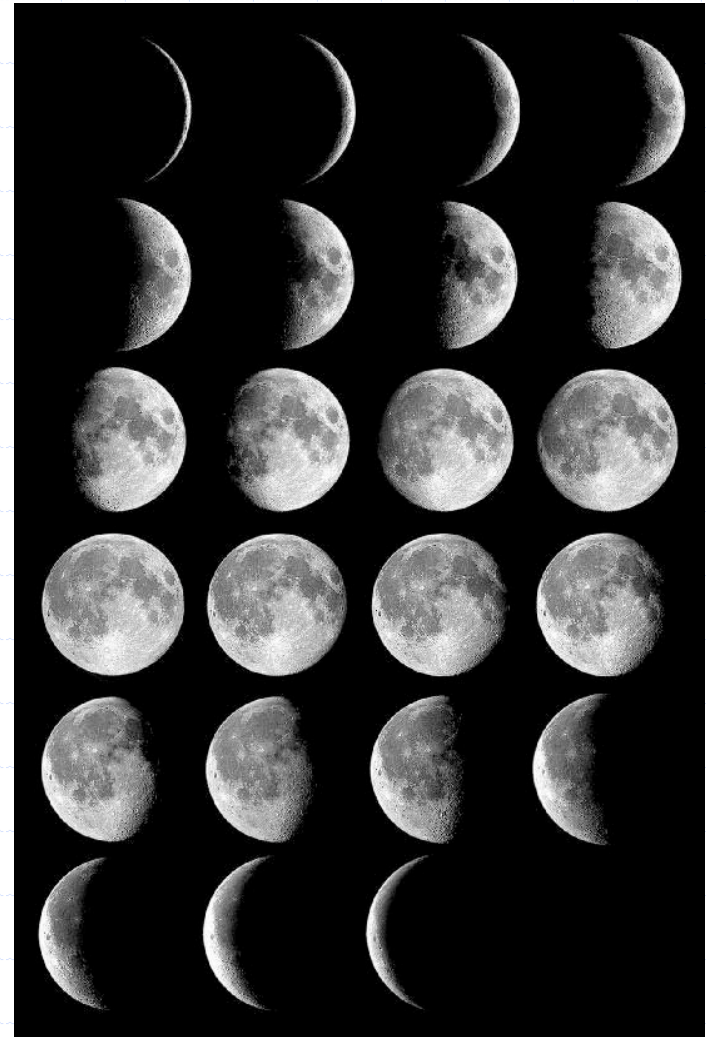
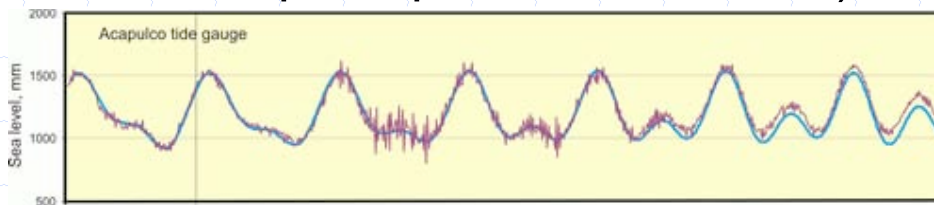


# Describing complex systems; Informing action

....e.g., the moon's effect on earth



Tides in Acapulco (tsunami 12/26/2004  
in red, superimposed on normals)



# Origins: Sea-level observation ("bench" is old word for shore)

Tasmanian coastal  
Benchmark c.1841

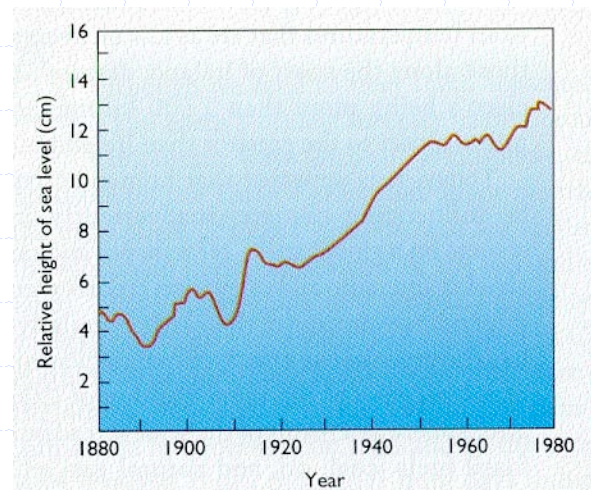
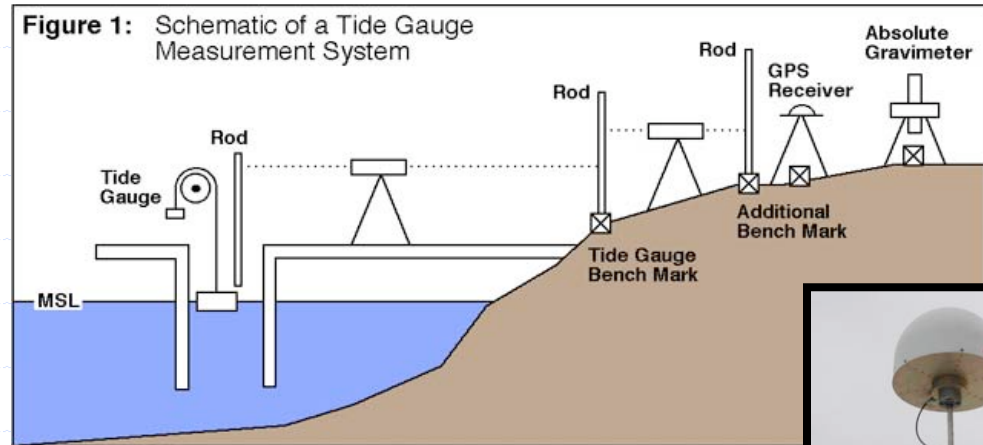
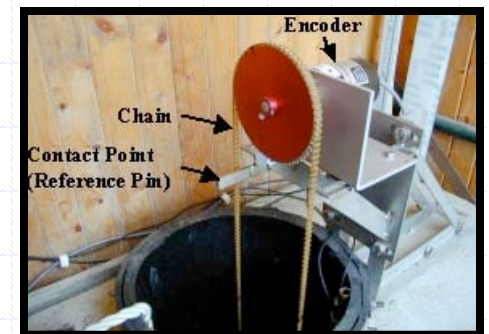
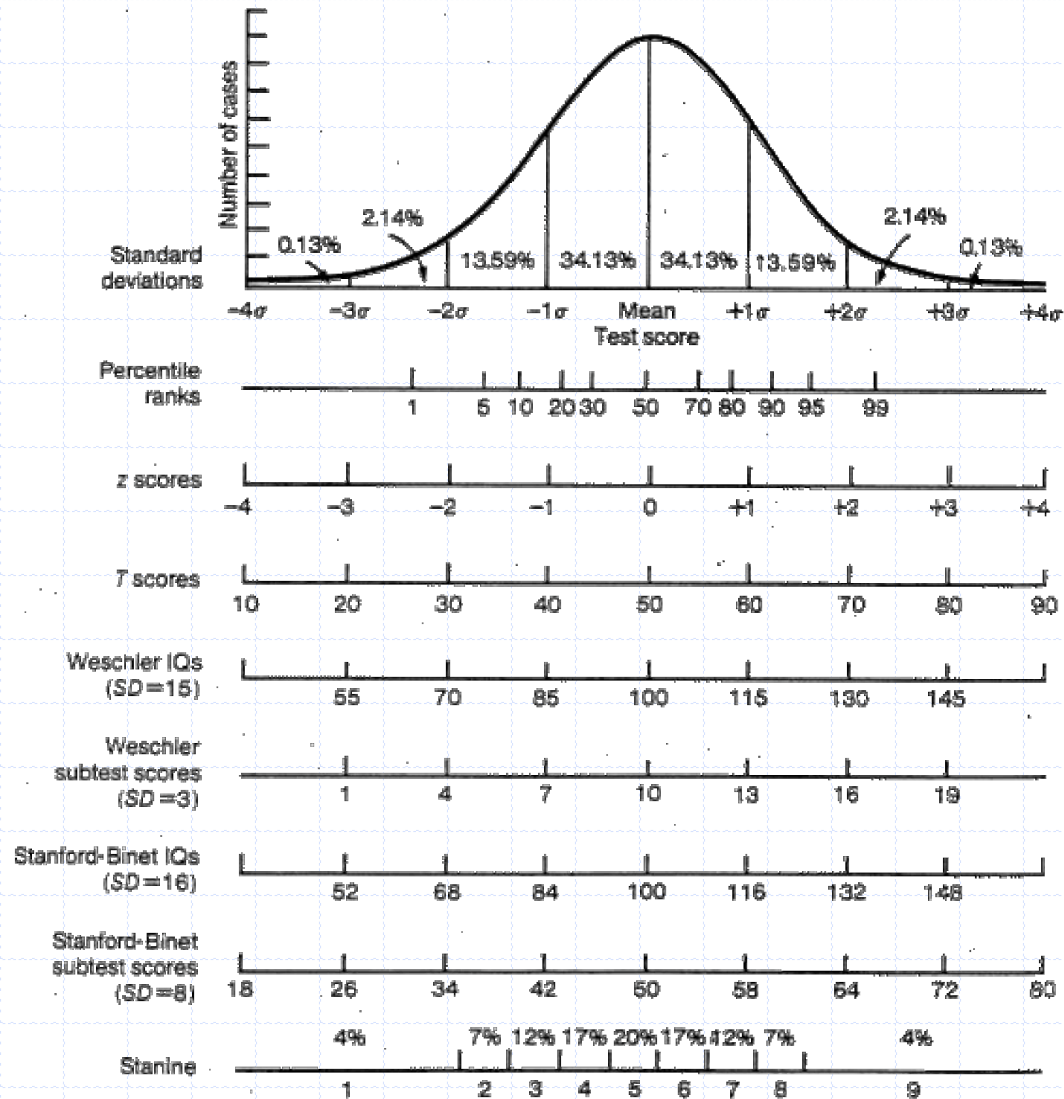


FIGURE 15-19

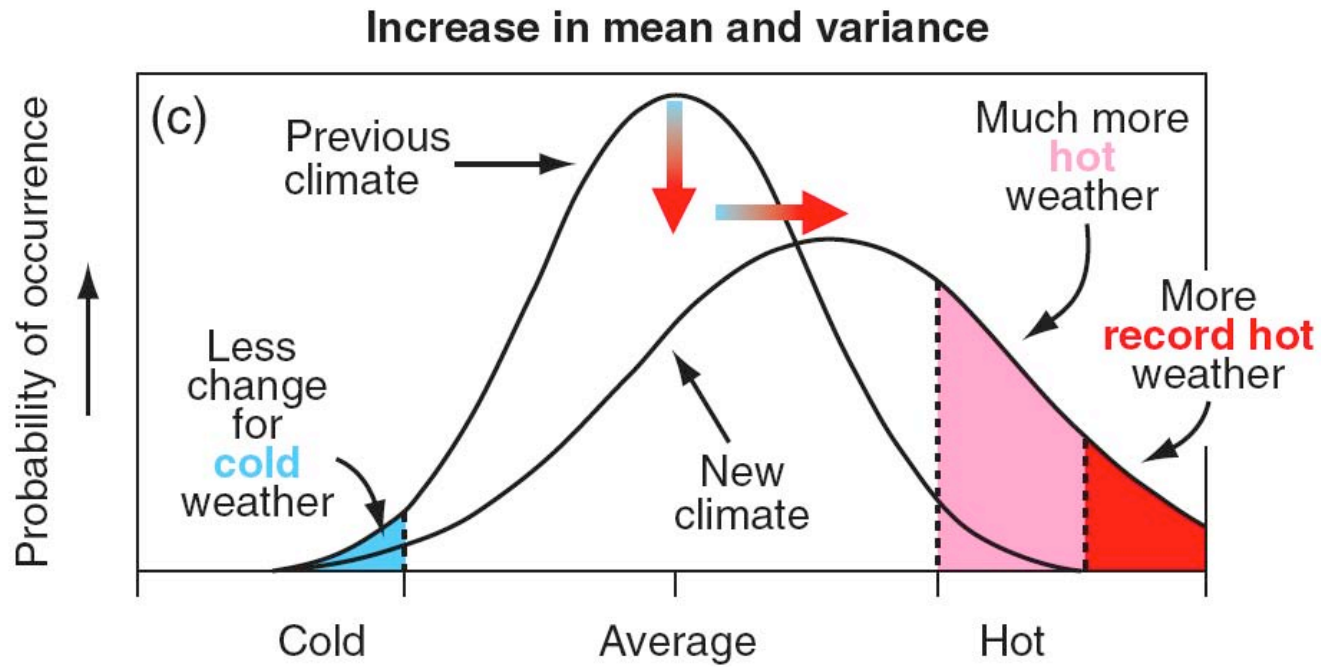
Sea levels. The recent global rise of sea level. [Adapted from V. Gornits, S. Lebedeff, and J. Hausen, *Science* 215 (1982): 1611-14.]



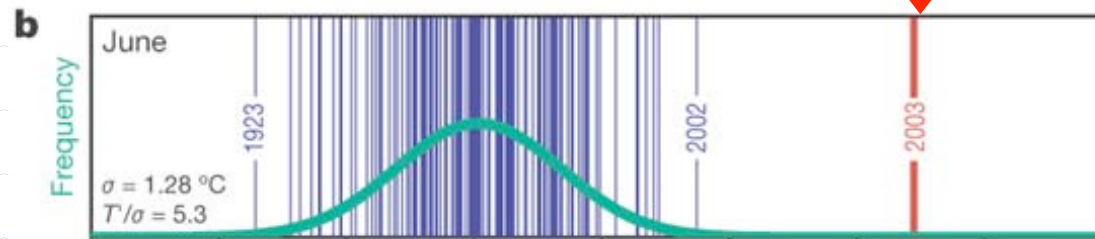
# Familiar Benchmarks: IQ



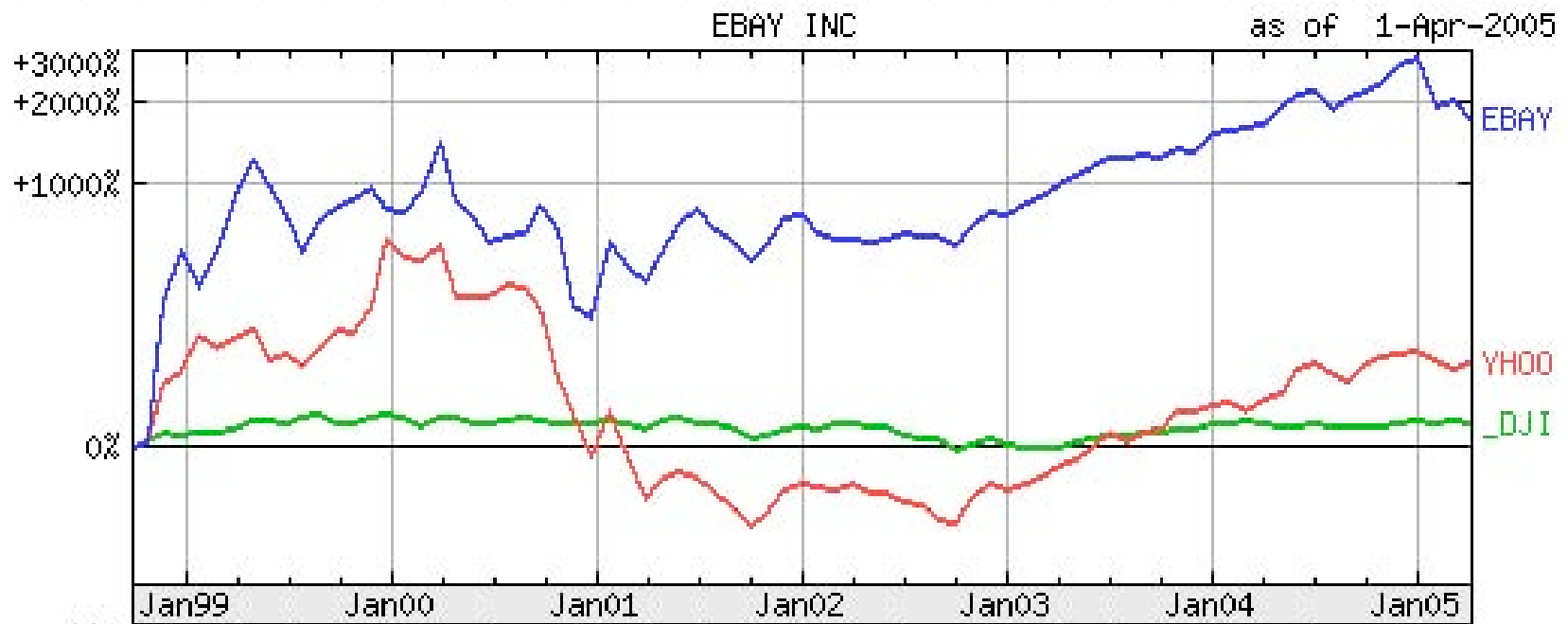
# Climate Change



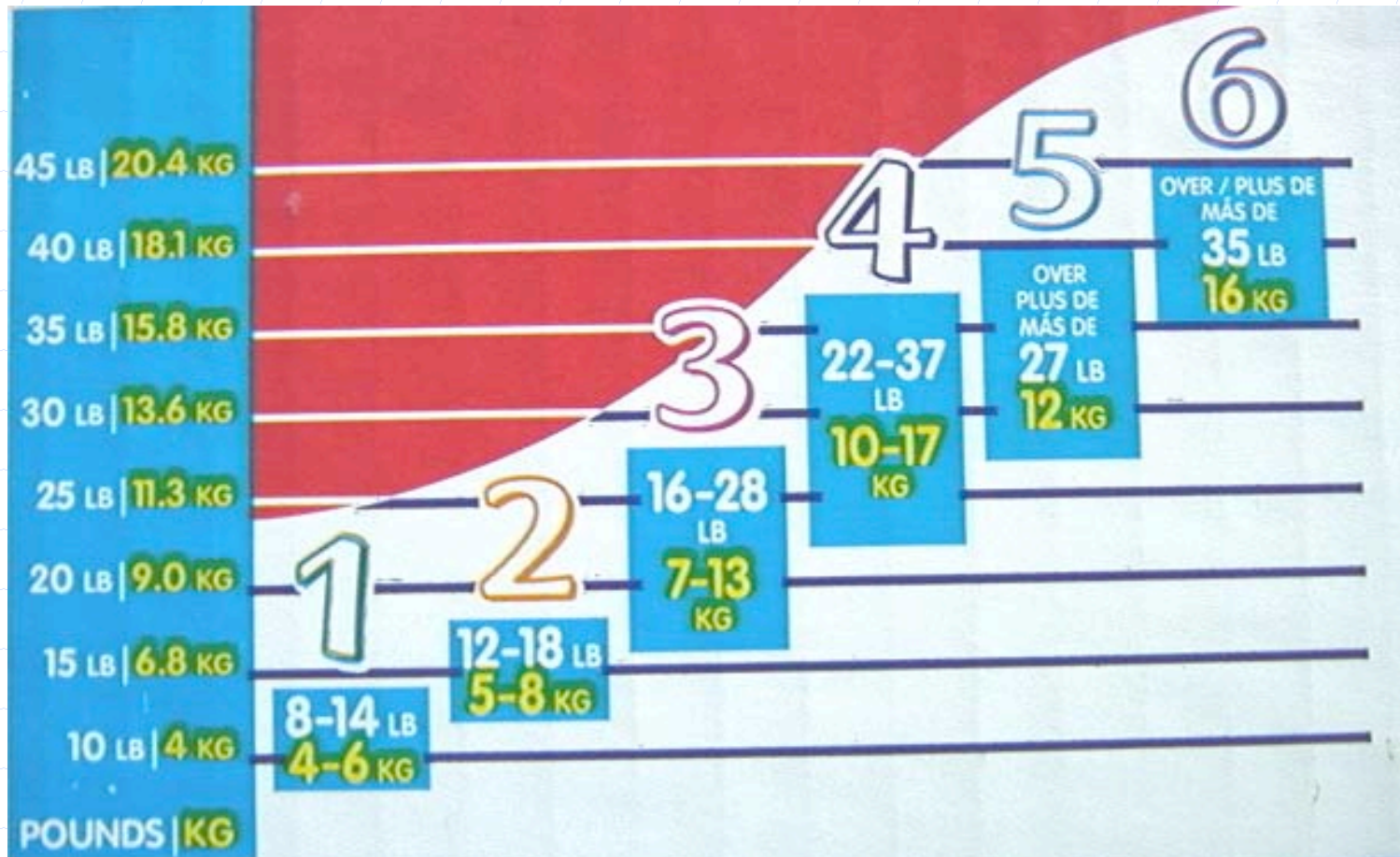
Europe Summer Temperatures: 2003



# Benchmarks are Everywhere



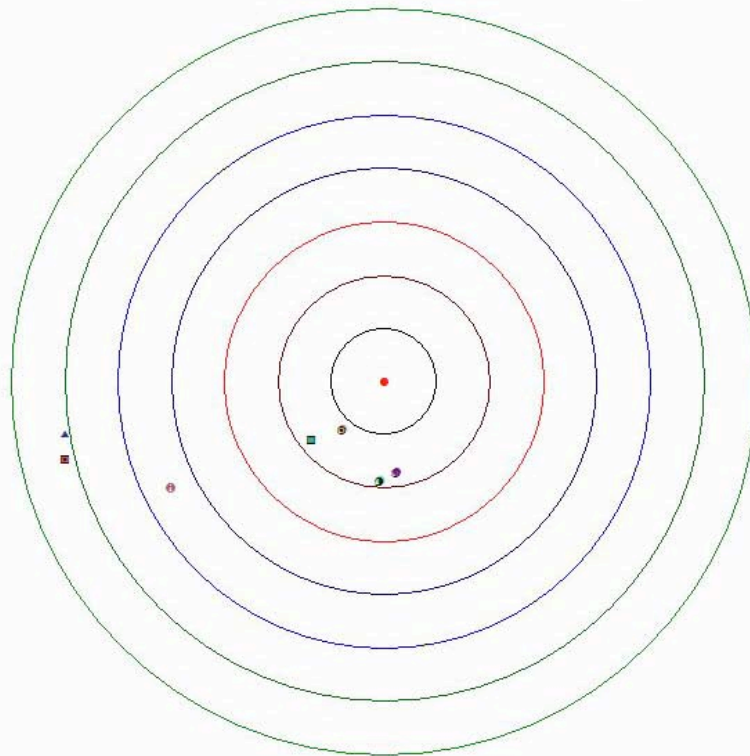
# Huggies: Diaper Size as Function of Child Weight



Nice chart; dubious value in real world  
(parents don't pick diapers based on child's weight)

# Bullseye

## GPS Accuracy Comparisons



Rings are spaced at 2m intervals

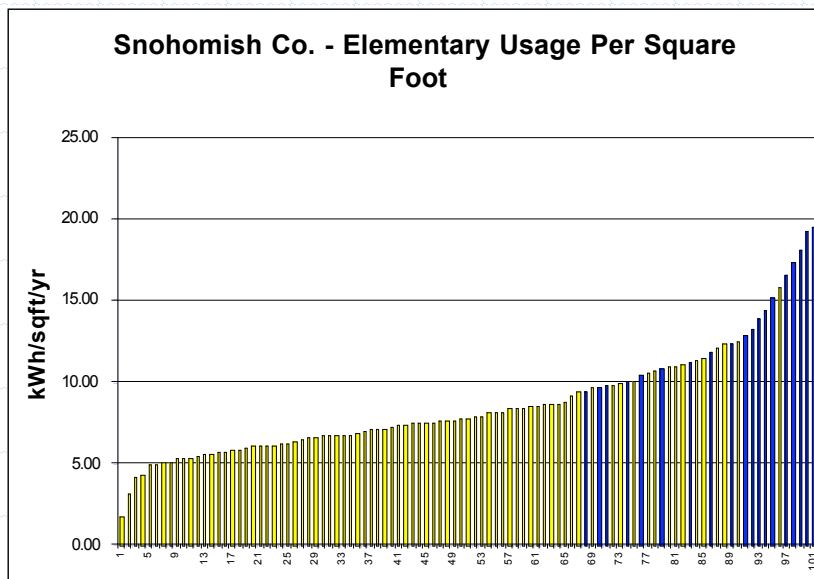
- Final Bench Point
- ▲ Rhino
- Proxrs waas
- Proxrs corrected
- Map76 waas
- Map76
- Geoxt waas
- Geoxt diff. corrected
- Etrax legend
- ∩ Roads

0.01      0      0.01      0.02 Kilometers





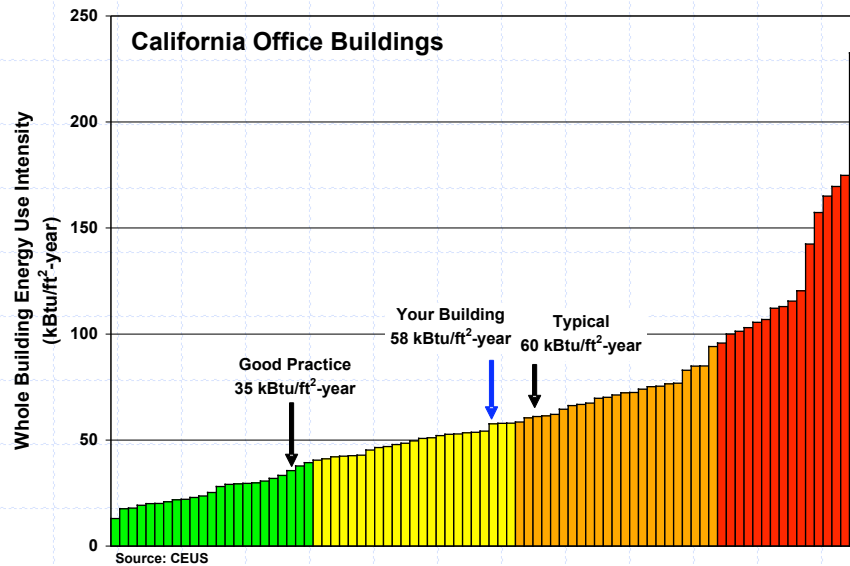
# Why Benchmark Energy Use?



- ◆ Establish baseline and track performance
- ◆ Validate design
- ◆ Identify best practices; set goals or standards
- ◆ Identify savings potential
- ◆ Prioritize efforts
- ◆ Identify maintenance and control problems
- ◆ Educate; Inspire!

*Energy benchmarking is one part of a broader energy management process*

# Many possible metrics



- ◆ Energy
  - ∨ (e.g. kBtu/ft<sup>2</sup>-degree day)
- ◆ Single fuel
- ◆ Peak power
- ◆ Cost
- ◆ Emissions
- ◆ “Unit-less” point systems
- ◆ Service level

# Many approaches

- ◆ Statistical (bell curve; vs. population)
- ◆ Point-estimates (vs. population avg.)
- ◆ Point-based (vs. best practice)
- ◆ Model-based (actual vs. efficient)
- ◆ Standardized (vs. test procedure)

Scope: self-referential; enterprise; stock;  
relationship to codes

Timeframe: historic trends vs. current

# Familiar Energy Benchmarks ...

...Fundamental differences in approach



Sample Fuel Economy Label  
(Attached to New Vehicle Window)

This is the average estimate for city driving

Use these two estimates to compare to other models

Compare this vehicle to others by using the FREE GAS MILEAGE GUIDE available in the dealer showroom

CITY MPG

Actual Mileage will vary with options, driving conditions, driving habits and vehicle's condition. Results reported to EPA indicate that the majority of vehicles with these estimates will achieve between 13 and 18 mpg in the city, and between 21 and 28 mpg on the highway.

1992 CANARY 2.8 LITER V6 ENGINE 2 BBL CARB MAN 4 SPD TRANS CATALYST, FEEDBACK FUEL

Estimated Annual Fuel Cost \$942

HIGHWAY MPG

For Comparison Shopping all vehicles classified as COMPACT have been issued mileage ratings ranging from 12 to 37 mpg city and 20 to 40 mpg highway.

These numbers represent a range of fuel economy that most drivers achieve with this particular model.

These numbers represent the range of fuel economy for other models of this size class.

This fuel cost is based on 15,000 mi/yr at \$1.20

Based on standard U.S. Government tests

## ENERGYGUIDE

Clothes Washer  
Capacity: Standard  
Top Loading

XYZ Corporation  
Model(s) MP420L, XL12, KAA83

Compare the Energy Use of this Clothes Washer with Others Before You Buy.

This Model Uses  
**873 kWh/year**

Energy use (kWh/year) range of all similar models

Uses Least Energy **257**      Uses Most Energy **1818**

kWh/year (kilowatt-hours per year) is a measure of energy (electricity) use. Your utility company uses it to compute your bill. Only standard size, top loading clothes washers are used in this scale.

**Clothes washers using more energy cost more to operate. This model's estimated yearly operating cost is:**

**\$72**

when used with an electric water heater

**\$28**

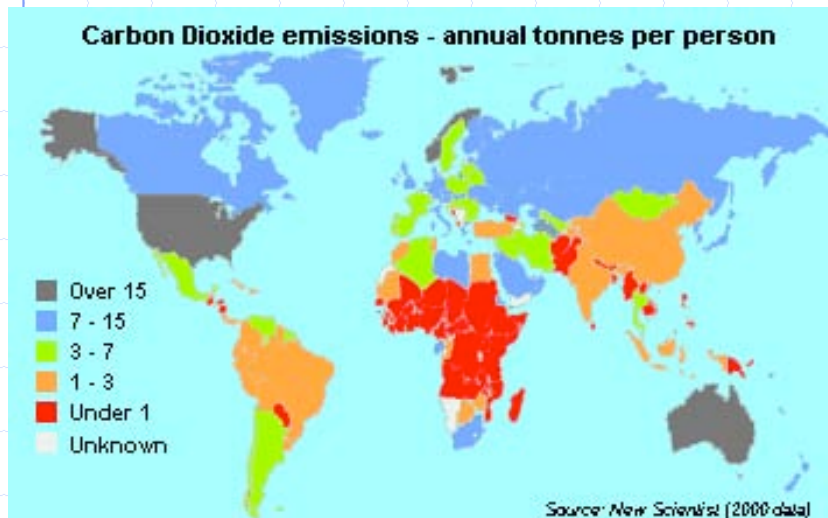
when used with a natural gas water heater

Based on eight loads of clothes a week and a 1992 U.S. Government national average cost of 8.25¢ per kWh for electricity and 52¢ per therm for natural gas. Your actual operating cost will vary depending on your local utility rates and your use of the product.

Standard Method of Test before consumer purchase. © 1992 U.S. Dept. of Energy.

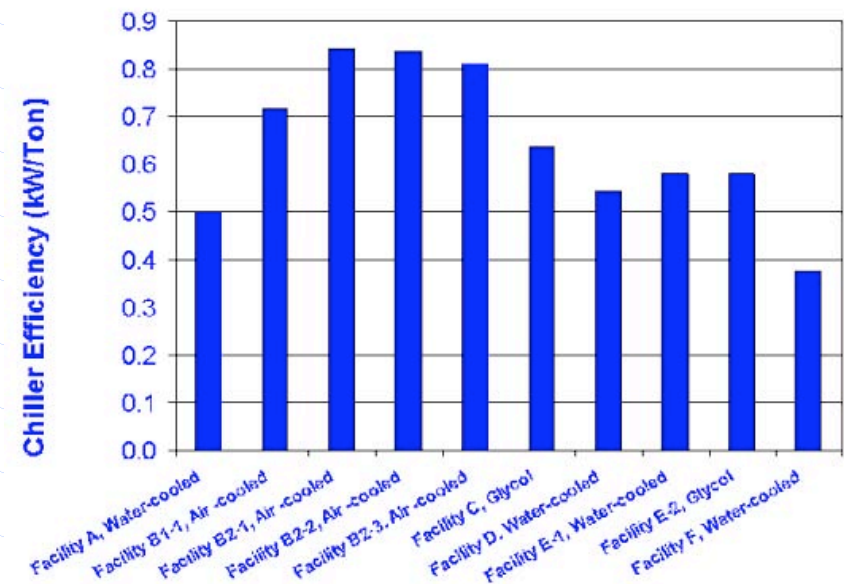
# Benchmarking Can Be Done at Any Scale

- Global CO2/Capita

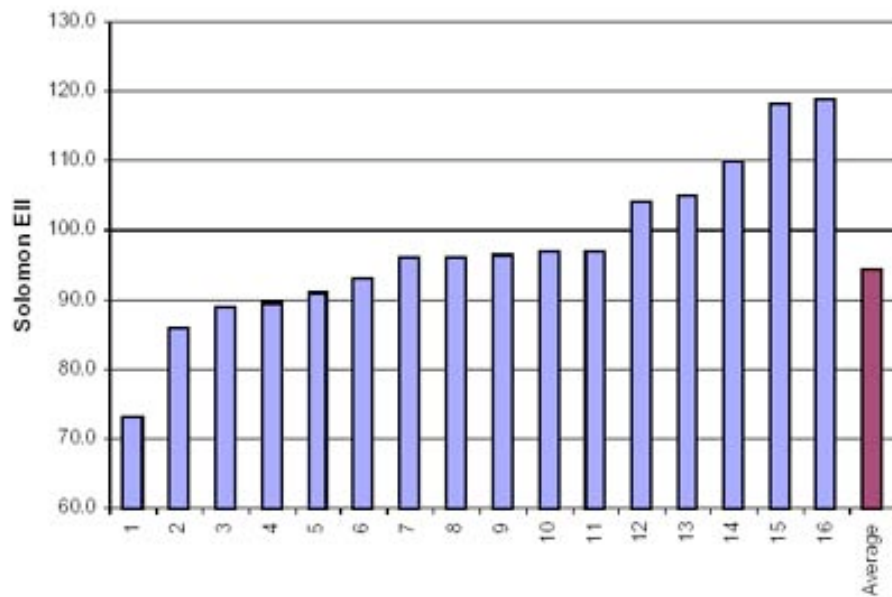


- Chiller efficiency

Chiller  
efficiency



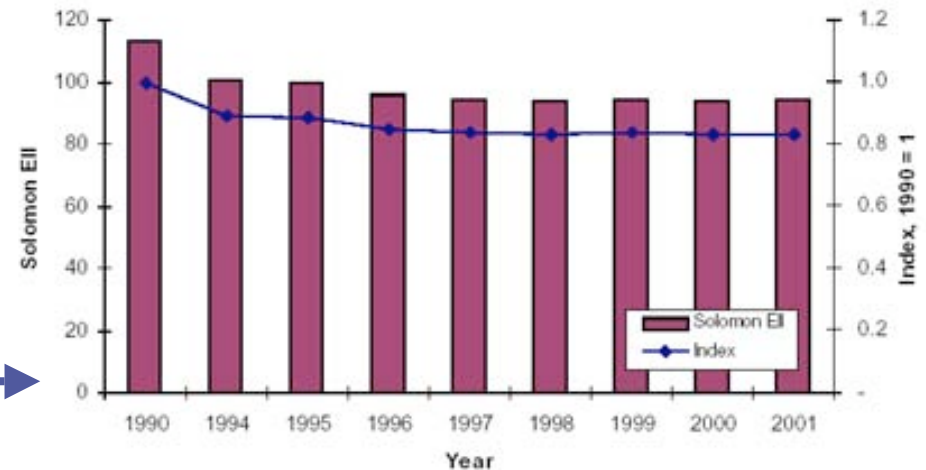
# Lateral vs. Longitudinal: e.g. Oil Refineries



Solomon Energy Intensity Index of Participating Individual Refineries  
Source: CIEEDAC, 2002.

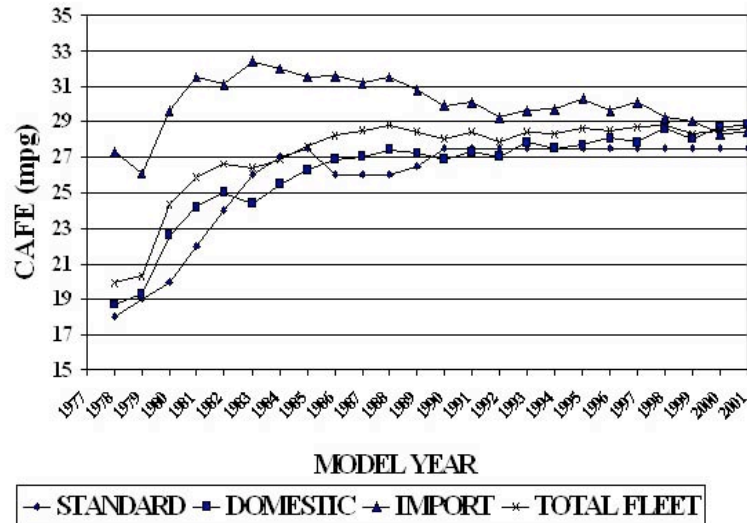
← Comparing “peers” at one point in time

Following “fleet-wide” trends over time →



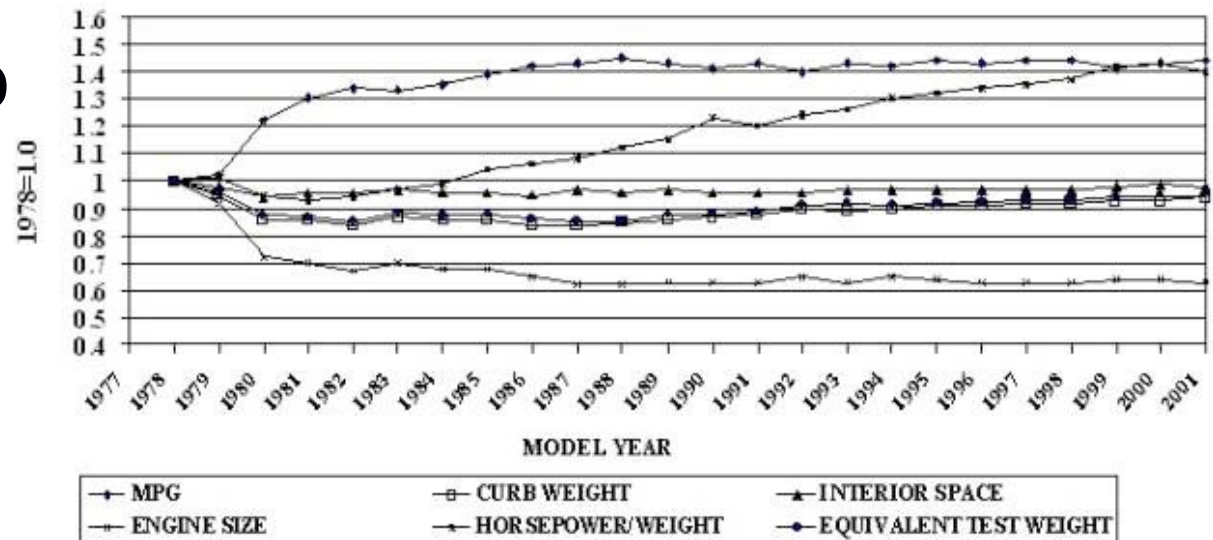
Average Refinery Energy Intensity based on a composite of Solomon EII for all known refineries.<sup>4</sup>

# Decide What is Important Before Benchmarking



◆ Important to isolate sub-groups of interest

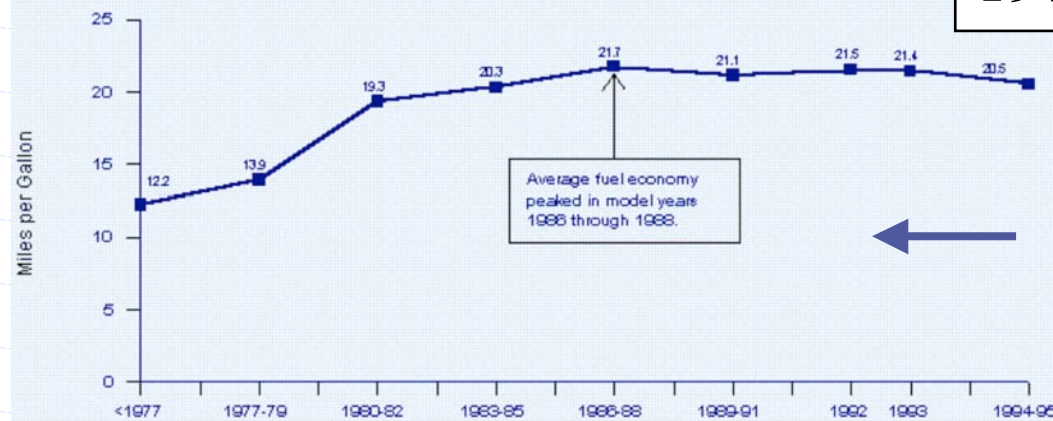
◆ Many ways to benchmark a given system



Source: NHTSA

# Choice of Benchmark Determines Conclusion

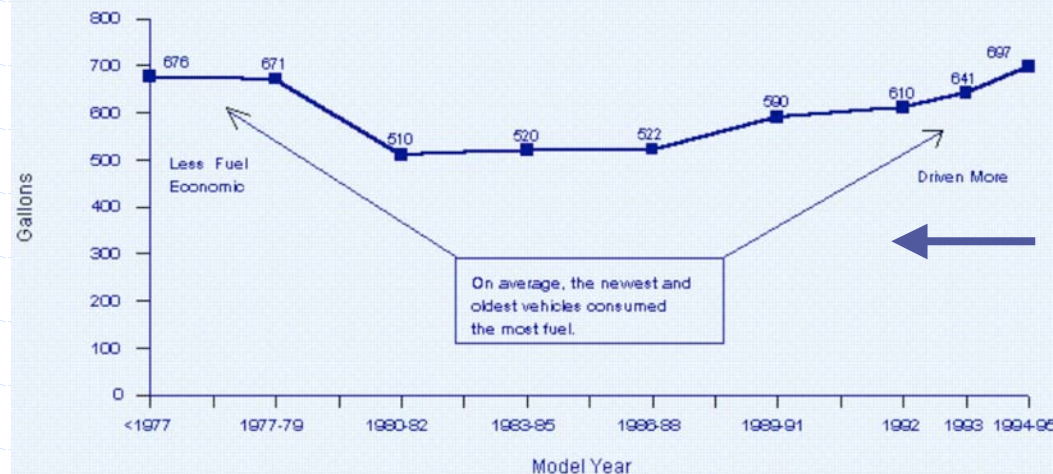
Figure 4.1 Average Fuel Economy of Residential Vehicles for Model Years Through 1995



1977-1995

Average US fuel economy increasing, then flat

Figure 4.9 Average Residential Vehicle Fuel Consumption per Vehicle for Model Years Through 1995



Average US vehicle fuel use declining, then rising

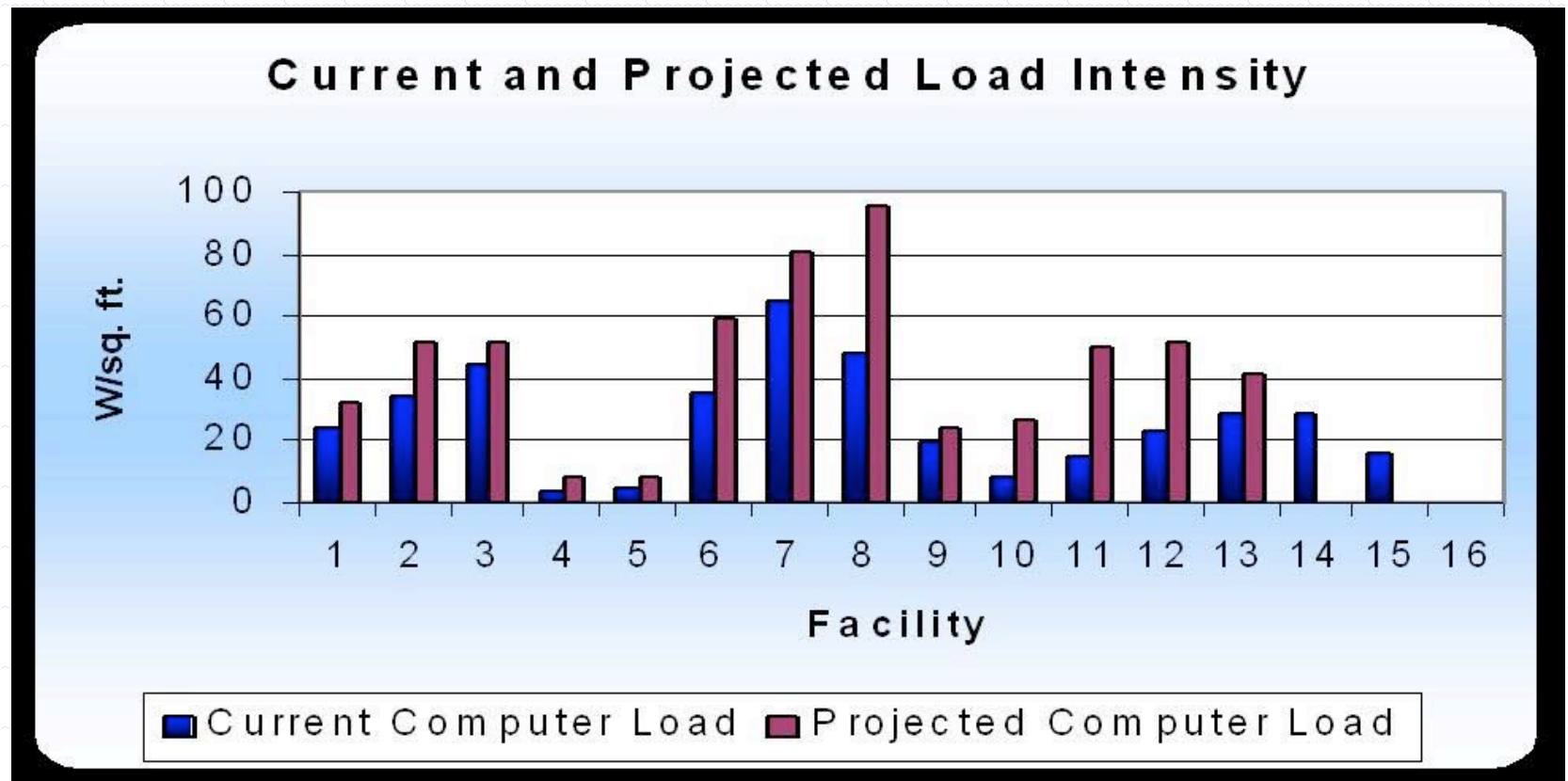
Source: USDOE/EIA



# Benchmarks Can Provide a “Reality Check” for planners

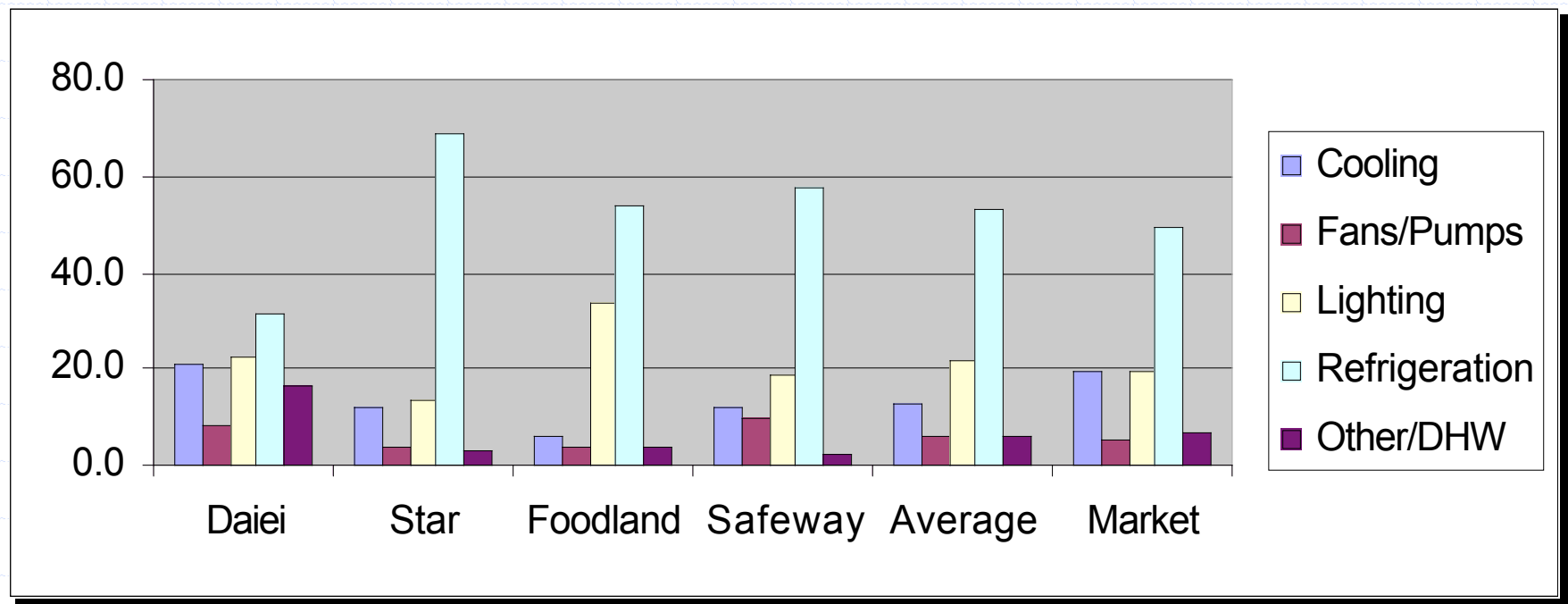
California Data Center owners claim a need of 250 W/ft<sup>2</sup>

Real data benchmarks the actual need between 10 and 100.



# End-Use Intensities

## Hawaiian Grocery Stores (kWh/ft<sup>2</sup>-year)



Source: HECO, Thomas D. Van Liew

# Intensities x Enterprise

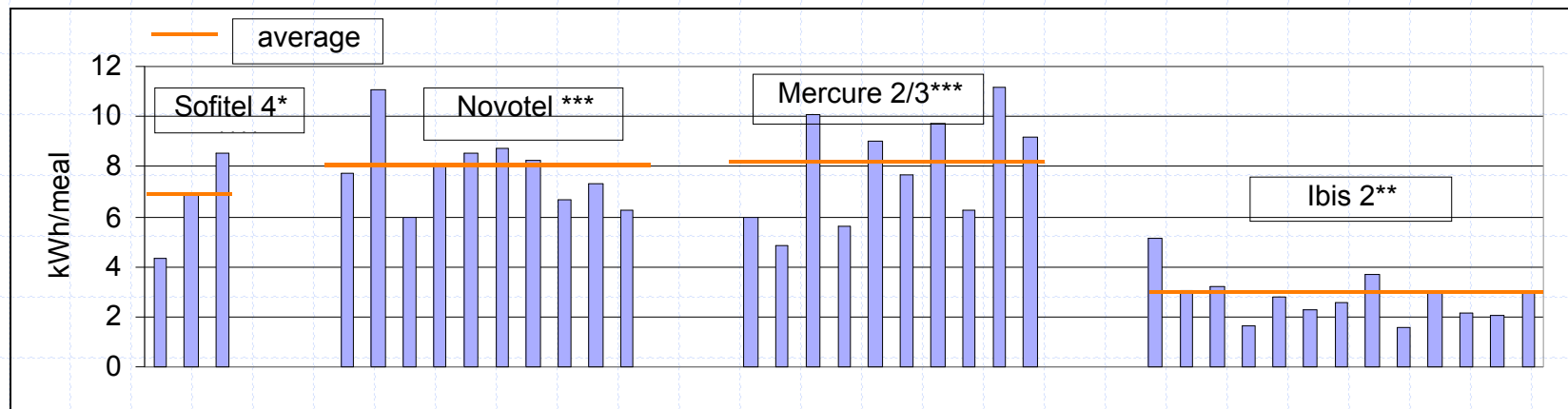
## Energy per meal for 36 hotels, France

Std. Dev. 34%

27%

19%

32%



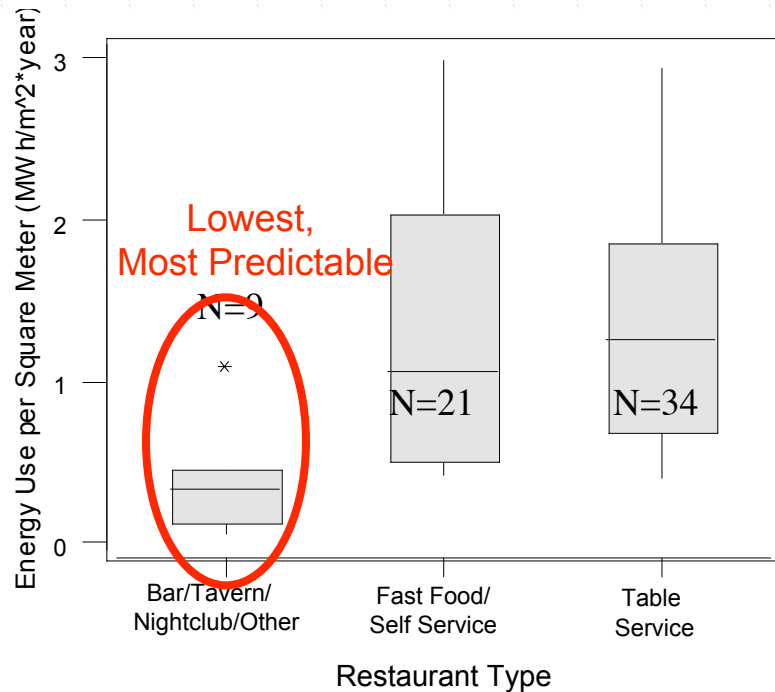
category of hotels	conservation kWh/meal	cooking kWh/meal	dishwashing kWh/meal	total kWh/meal	standard deviation
2**	0.44	2.08	0.25	2.77	0.94
2**/3***	3.81	3.89	0.25	7.95	2.18
3***	3.67	3.99	0.21	7.86	1.47
4****	2.53	3.92	0.13	6.58	2.13

Source: Le Strat et al., (1999)

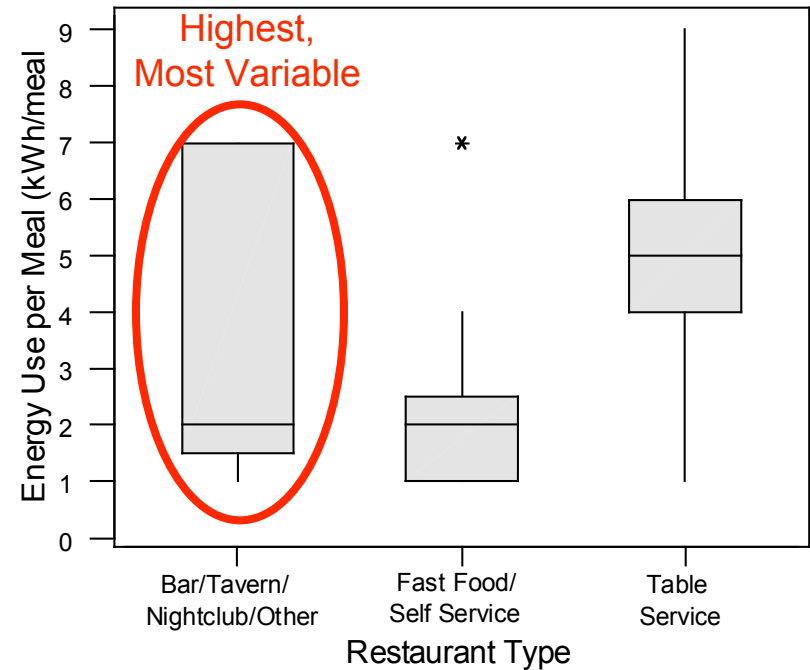
# Choice of Indicator is Key

## Restaurants

### Energy per unit floor area



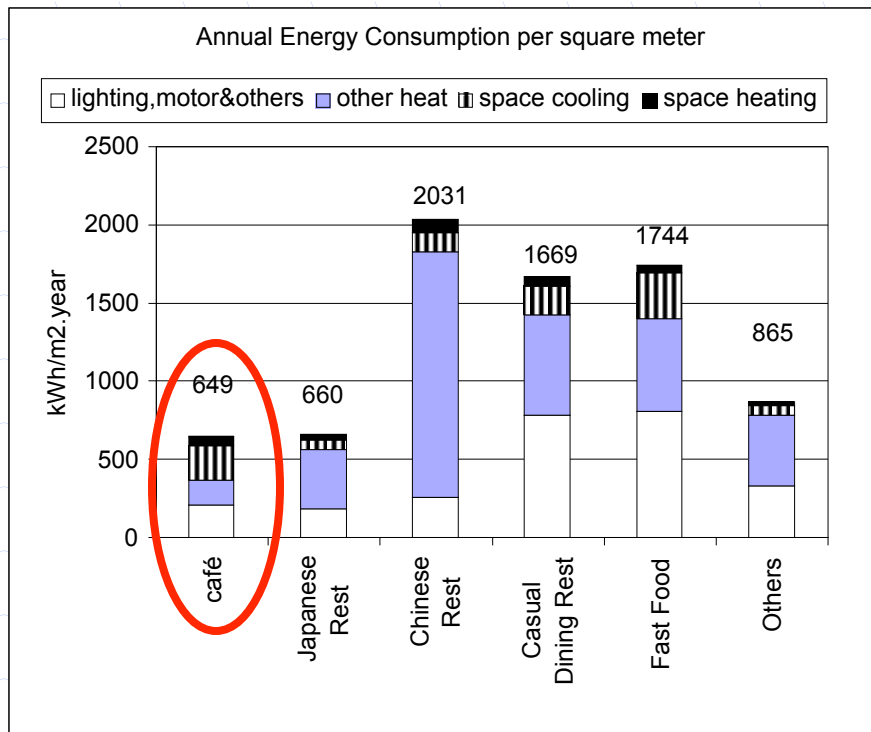
### Energy per meal



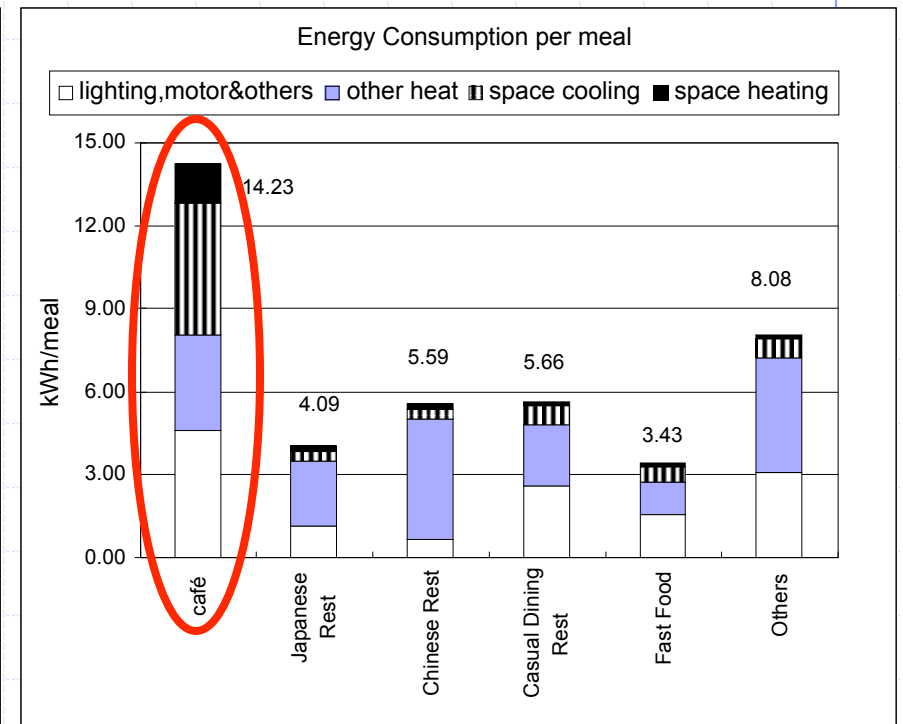
Source: 1996 California Commercial End Use Survey

# Choice of Indicator is Key

## Energy per unit floor area



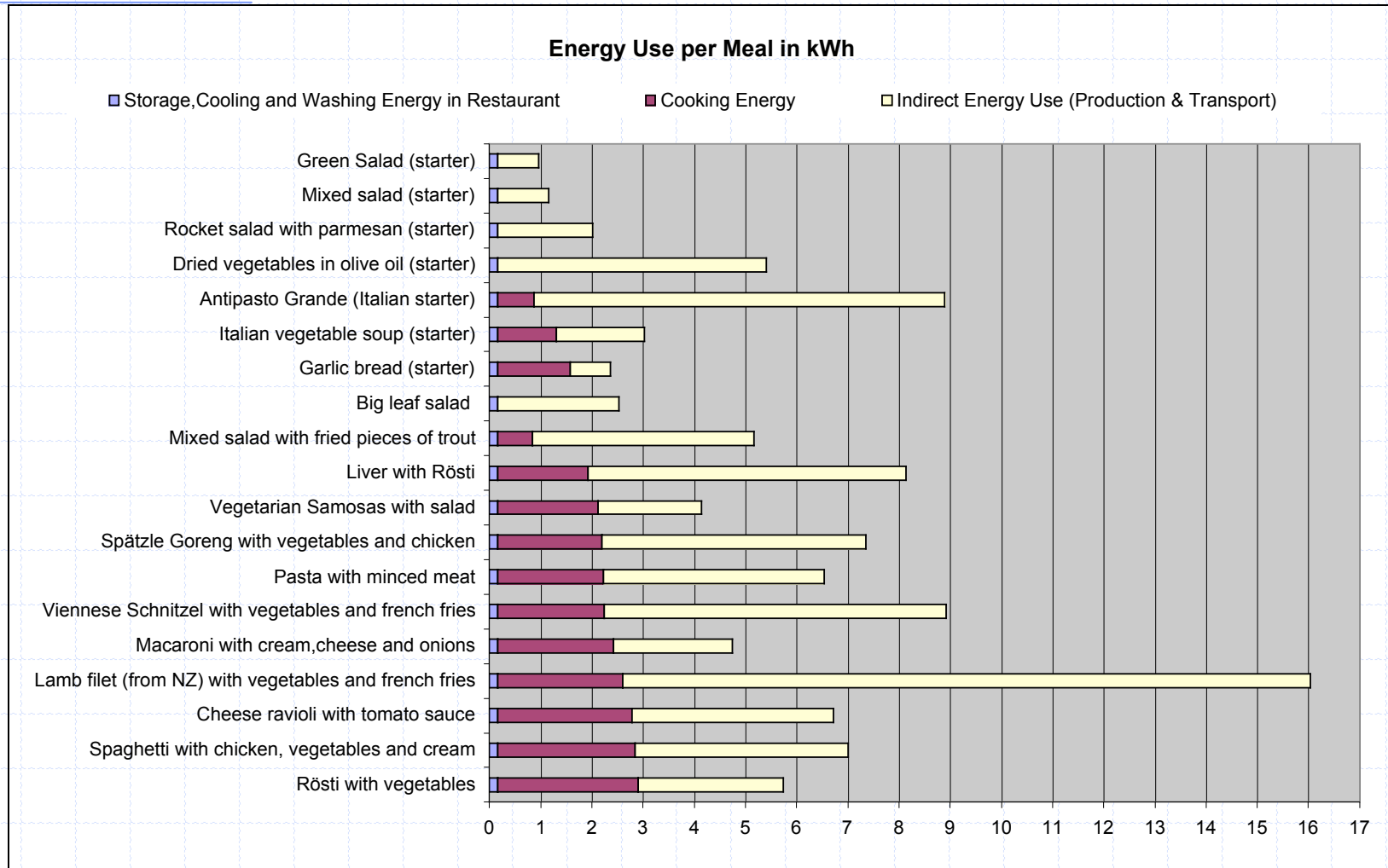
## Energy per meal



Café ranks “best” by one benchmark and “worst” by the other

Source: The Energy Data and Modeling Center, 2001

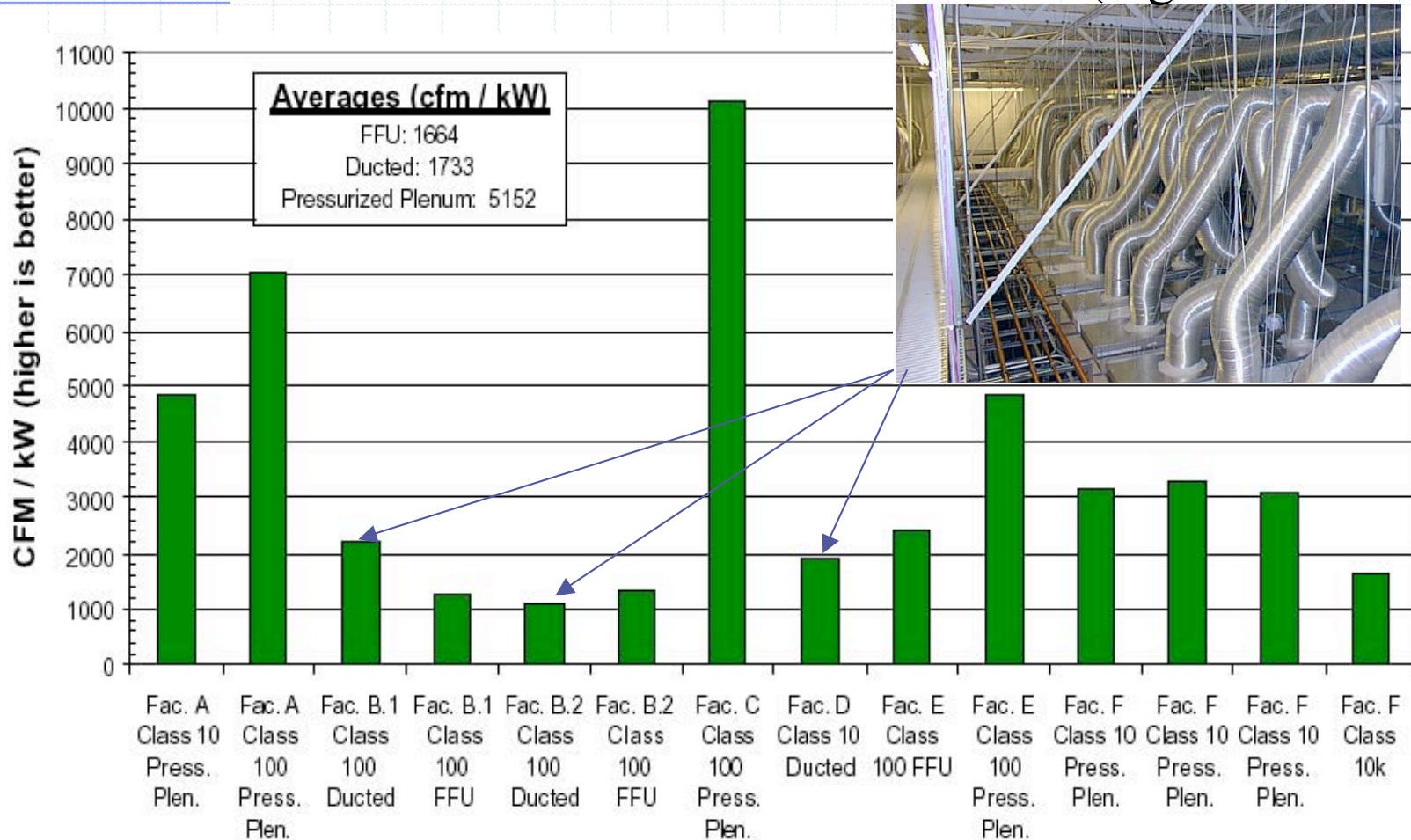
# Beyond “Apples & Oranges”: Pippins and Granny Smiths



Data for Switzerland. Source: Balmer and Hintermann, 2000

# Delivery of Service Levels: Cleanrooms

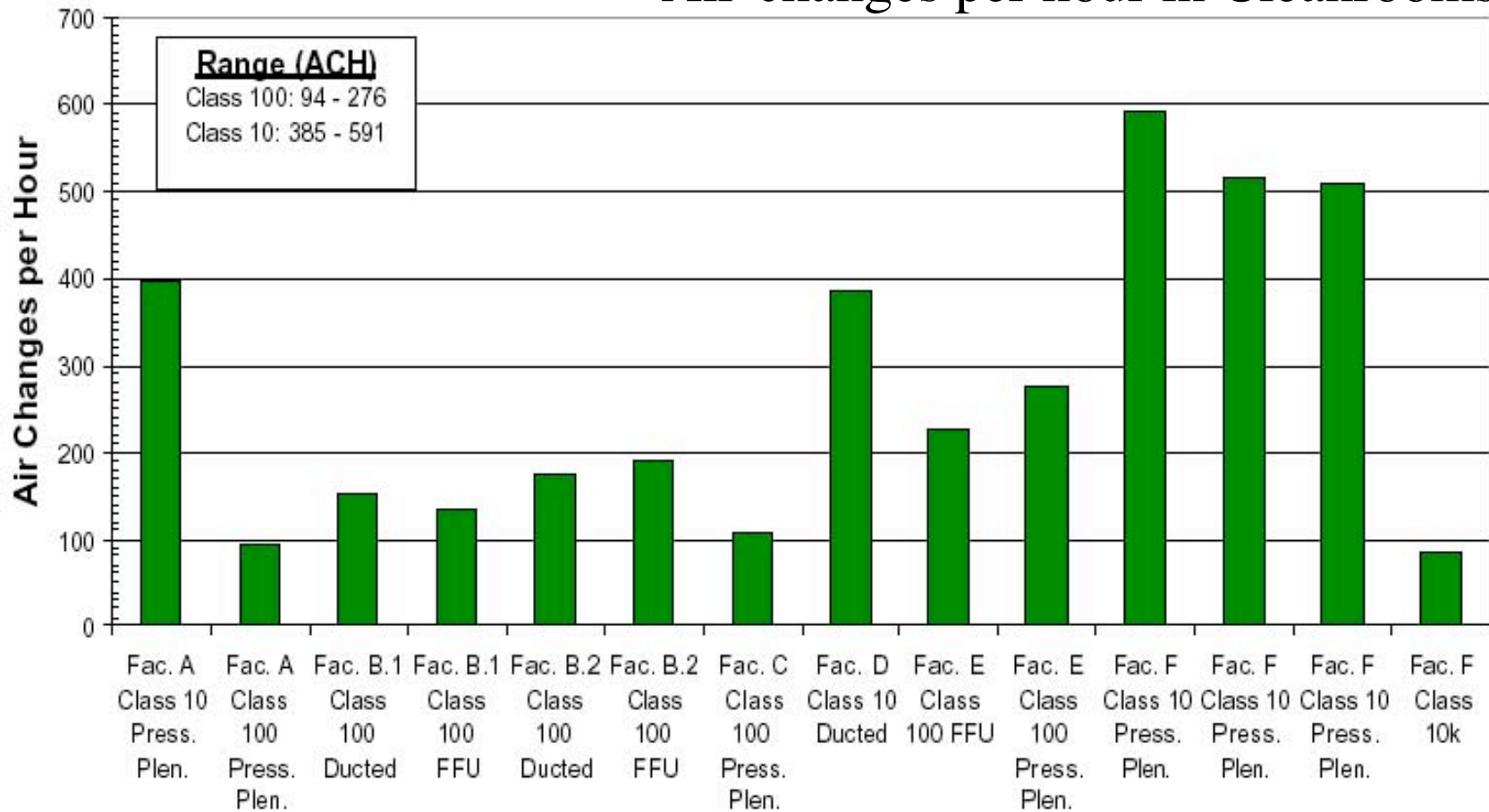
Air movement CFM/kW (higher is better)



Tschudi and Xu, *ASHRAE Transactions*, KC-03-9-4 (2003)

# Some “Energy” Benchmarks Don’t Even Include Energy

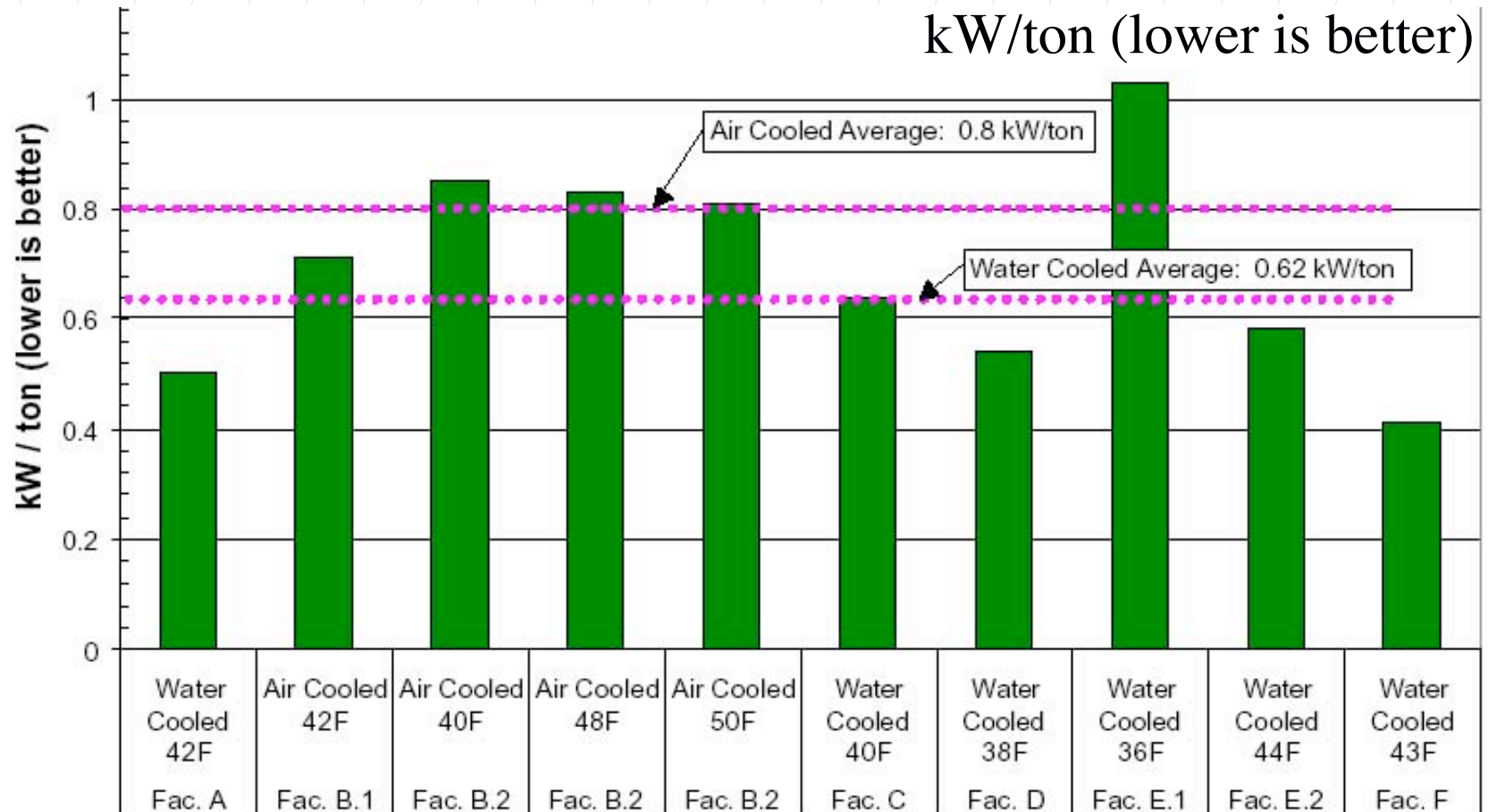
## Air-changes per hour in Cleanrooms



Tschudi and Xu, *ASHRAE Transactions*, KC-03-9-4 (2003)



# Component Benchmarking: Cleanroom Chiller Efficiencies



Tschudi and Xu, *ASHRAE Transactions*, KC-03-9-4 (2003)

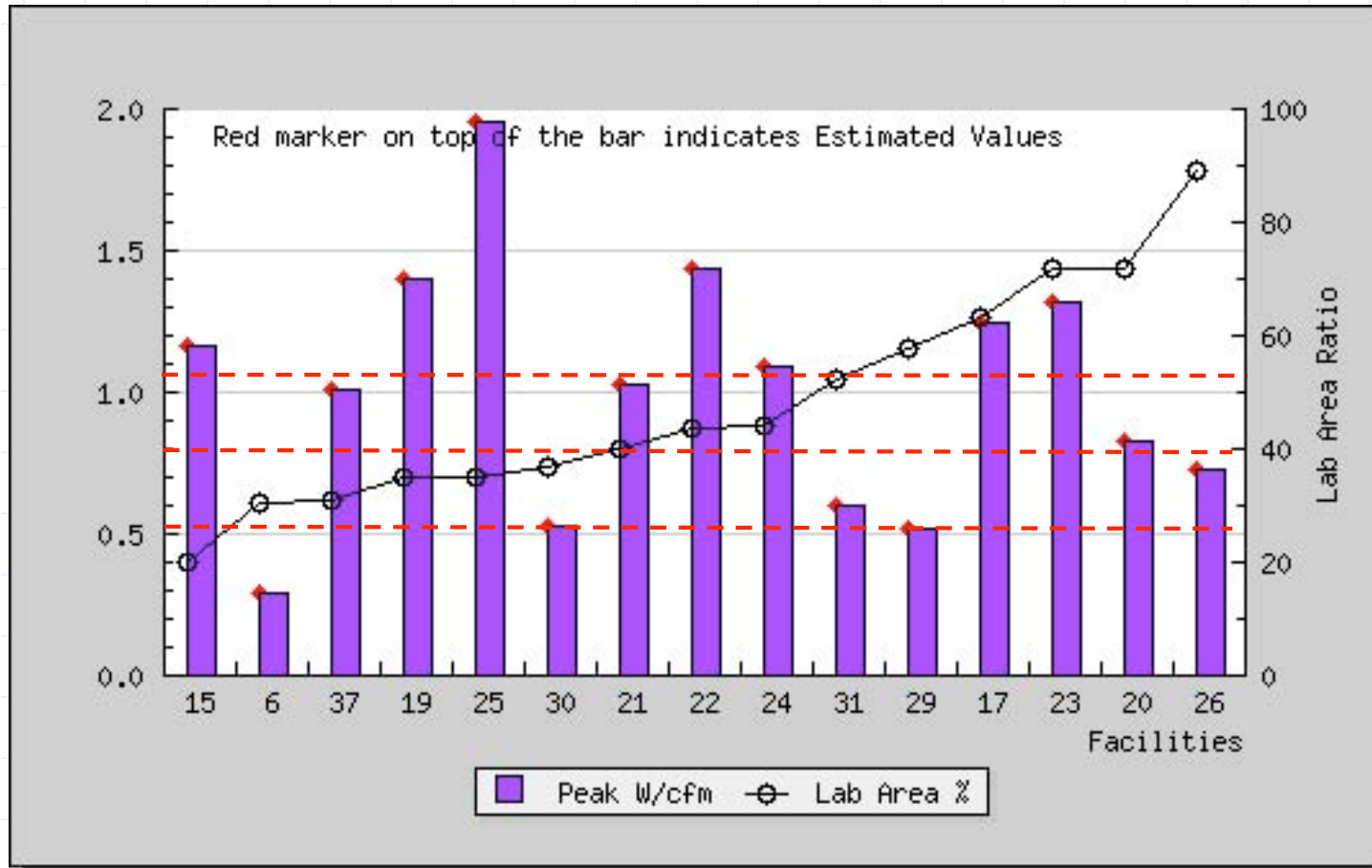
# Cleanroom Energy Metrics

•Recirculation air handler efficiency	•cfm/kW
•Makeup air handler efficiency	•cfm/kW
•Annual energy cost per cleanroom square foot	•\$/ft <sup>2</sup>
•Annual fuel usage	•MBtu/ft <sup>2</sup> -yr
•Annual electricity usage	•kWh/ft <sup>2</sup> -yr
•Annual energy usage	•MBtu/ft <sup>2</sup> -yr
•Makeup air	•cfm/ft <sup>2</sup>
•Recirculation air	•cfm/ft <sup>2</sup> or ach
•Chiller efficiency	•kW/ton
•Tower efficiency	•kW/ton
•Condenser water pump efficiency	•kW/ton
•Chilled water pump efficiency	•kW/ton
•Total chilled-water plant efficiency	•kW/ton
•Hot water pumping efficiency	•kW/MBtu
•Cooling load density	•ft <sup>2</sup> /ton

Tschudi and Xu, *ASHRAE Transactions*, KC-03-9-4 (2003)

# From Benchmarking to Best Practices

## Laboratory Ventilation W/cfm

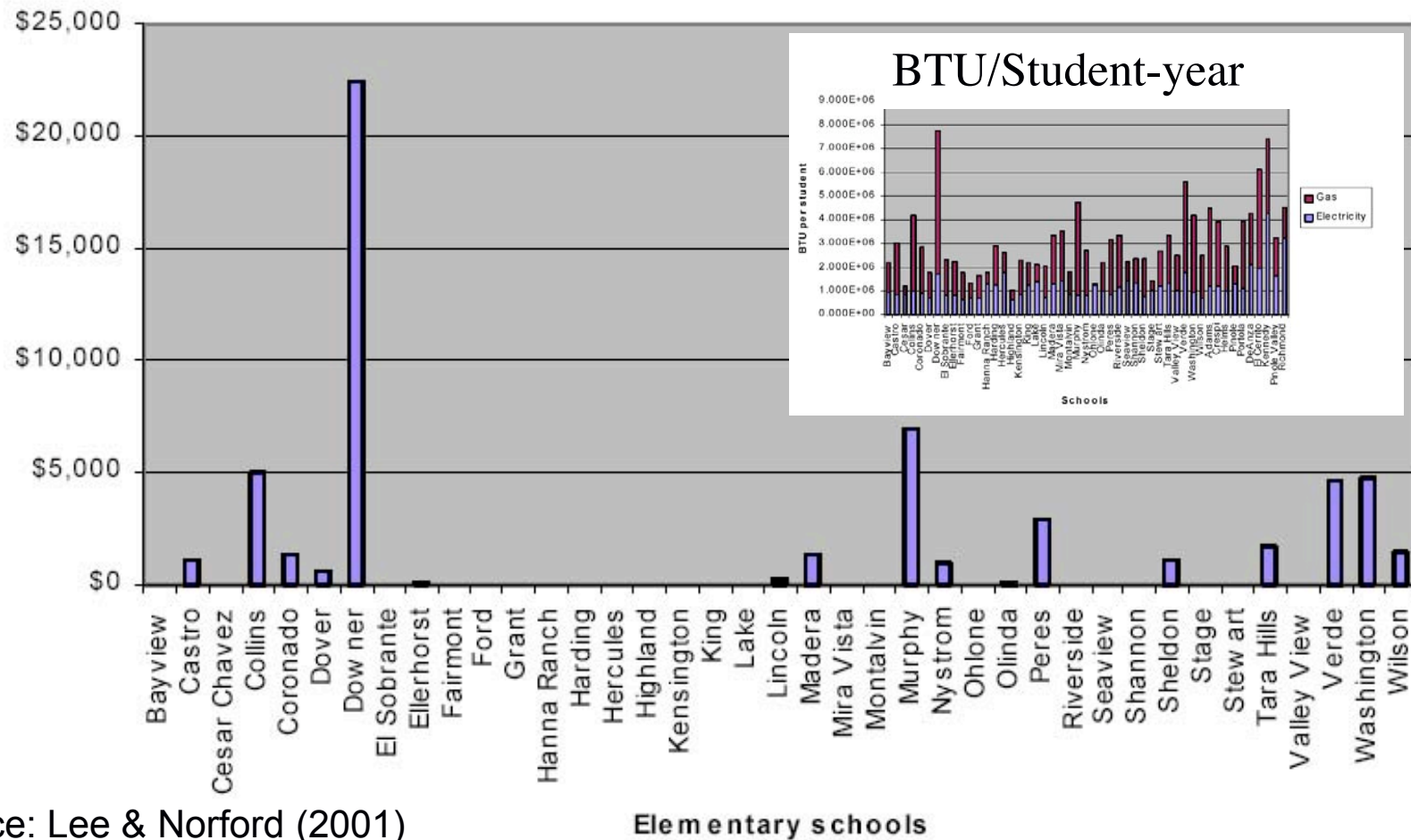


*standard*  
*good*  
*better*

Standard, good, better benchmarks as defined in  
"How-low Can You go: Low-Pressure Drop Laboratory Design"  
by Dale Sartor and John Weale, ASHRAE Journal

# Benchmarks as Screening Tool

## Gas \$ Savings if Brought to Median Value



Source: Lee & Norford (2001)

Elementary schools

# Labs21 Benchmarking Tool Analysis

Benchmarking Labs for the 21st Century Web Toolkit - Microsoft Internet Explorer

Address: <http://www.dc.lbl.gov/Labs21/CompareData.php?UserID=2>

**LABS FOR THE 21ST CENTURY**

**benchmarking**

Choose Metrics and Filtering Criteria  
[More Information](#)

User: **LBNL**  
 Organization: **Lawrence Berkeley National Laboratory**

Please specify the metric criteria -

System: Total Building  
 Energy / Efficiency Metric: BTU/sf-yr (site)

Please specify the filtering criteria -

1. Lab Area / Gross Area ratio is greater than or equal to 0.00 and is less than or equal to 0.99

2. Occupancy

- Standard ( $\leq 14$  hours)
- High ( $> 14$  hours)
- Both (all data)

3. Climate [Climate Code, Climate Type, Representative City]

[\(To view the map of climatic distribution\)](#)

<input checked="" type="checkbox"/> 1A, <b>Very Hot - Humid</b> (Miami, FL)	<input checked="" type="checkbox"/> 2A, <b>Hot - Humid</b> (Houston, TX)
<input checked="" type="checkbox"/> 2B, <b>Hot - Dry</b> (Phoenix, AZ)	<input checked="" type="checkbox"/> 3A, <b>Warm - Humid</b> (Memphis, TN)
<input checked="" type="checkbox"/> 3B, <b>Warm - Dry</b> (El Paso, TX)	<input checked="" type="checkbox"/> 3C, <b>Warm - Marine</b> (San Francisco, CA)
<input checked="" type="checkbox"/> 4A, <b>Mixed - Humid</b> (Baltimore, MD)	<input checked="" type="checkbox"/> 4B, <b>Mixed - Dry</b> (Albuquerque, NM)
<input checked="" type="checkbox"/> 4C, <b>Mixed - Marine</b> (Salem, OR)	<input checked="" type="checkbox"/> 5A, <b>Cool - Humid</b> (Chicago, IL)
<input checked="" type="checkbox"/> 5B, <b>Cool - Dry</b> (Bosie, ID)	<input checked="" type="checkbox"/> 6A, <b>Cold - Humid</b> (Burlington, VT)
<input checked="" type="checkbox"/> 6B, <b>Cold - Dry</b> (Helena, MT)	<input checked="" type="checkbox"/> 7, <b>Very Cold</b> (Duluth, MN)
<input checked="" type="checkbox"/> 8, <b>Subarctic</b> (Fairbanks, AK)	

Graphing - Microsoft Internet Explorer

Address: <http://www.dc.lbl.gov/Labs21/Graphing.php>

**LABS FOR THE 21ST CENTURY**

**benchmarking**

Graphing Data

User: **LBNL**  
 Organization: **Lawrence Berkeley National Laboratory**

Total Building BTU/sf-yr (site)

Facility	Total Building Site Energy Use (BTU)	Gross Area (sq.ft.)	BTU/sf-yr (site)	Lab Area Ratio	Occupancy Hours	Climate
8	12613440000	54962	229493.83	0.19	12	3C
15	184866190404	532602	347100.07	0.2	11	4C
6	14396064000	55903	257518.63	0.3	12	3C
7	12350320000	44152	279722.78	0.31	12	3C
5	21098712000	85761	246017.56	0.31	12	3C
19	40723337460	151435	268916.28	0.35	12	4B
30	51086744000	21048	242943.01	0.37	24	3C

# Capturing Benchmarks with Design Intent Documentation

**Design Intent Tool 1.0 - [LBNL Project Template for Laboratories]**

File

Introduction | Manage Project Files | Manage Template Files | User Guide | Feedback | Help | Web Home Page

Design Intent Document | Owner's Goals & Project Info | Team Contact Info | Reports

**DESIGN INTENT TOOL**  
VERSION 1.0

Design Intent Tool 1.0  
Project Name: LBNL Project Ter  
Owner:  
Today's Date: 08-20-2002

Select Design Area  
+/- Add/Remove

- General
- Architectural: Loads
- Mechanical: Ventilation System
- Mechanical: Chiller Plant
- Mechanical: Heating Plant
- Electrical: Lighting System
- Electrical: Distribution System
- Electrical: Renewable/Distribut
- Process: Process/Plug Loads
- Operations and Maintenance

Design Area Description  
This area includes whole-building information or information pertaining to multiple design areas.

Select Objective  
+/- Details Click this button to add, remove or edit Objectives for this project

Objective Name	Objective Description
Achieve high overall energy efficiency	Energy efficiency is low energy consumption to accomplish a given task. High overall efficiency is low whole-building energy use (electric energy, peak electric power demand, natural gas, and any other fuels) to provide a laboratory building of a certain

Strategies  
+/- Details Click this button to add, remove or edit Strategies for the Objective selected above.

Index	Strategy Name	Strategy Description
1	Exceed Title 24 requirement by factor of 2.5 (energy use 40% of Title 24 budget)	Energy code requirements can typically be easily outperformed. Such requirements make a convenient baseline against which simulated performance can be compared. Title 24 is California's State Energy Code. Buildings can comply with the Code either by the prescriptive or
2	Achieve LEED Platinum rating	The Leadership in Energy and Environmental Design (LEED) system was created by the U.S. Green Building Council to comprehensively rate buildings for their environmental impact and sustainability. Platinum is the highest rating.
3	Minimize life-cycle cost	The life-cycle cost of a building is its total cost over its entire life, including design, construction, operation, maintenance, renovation, and decommissioning; future costs are discounted to present value for comparison. Minimizing life-cycle costs usually results in higher first

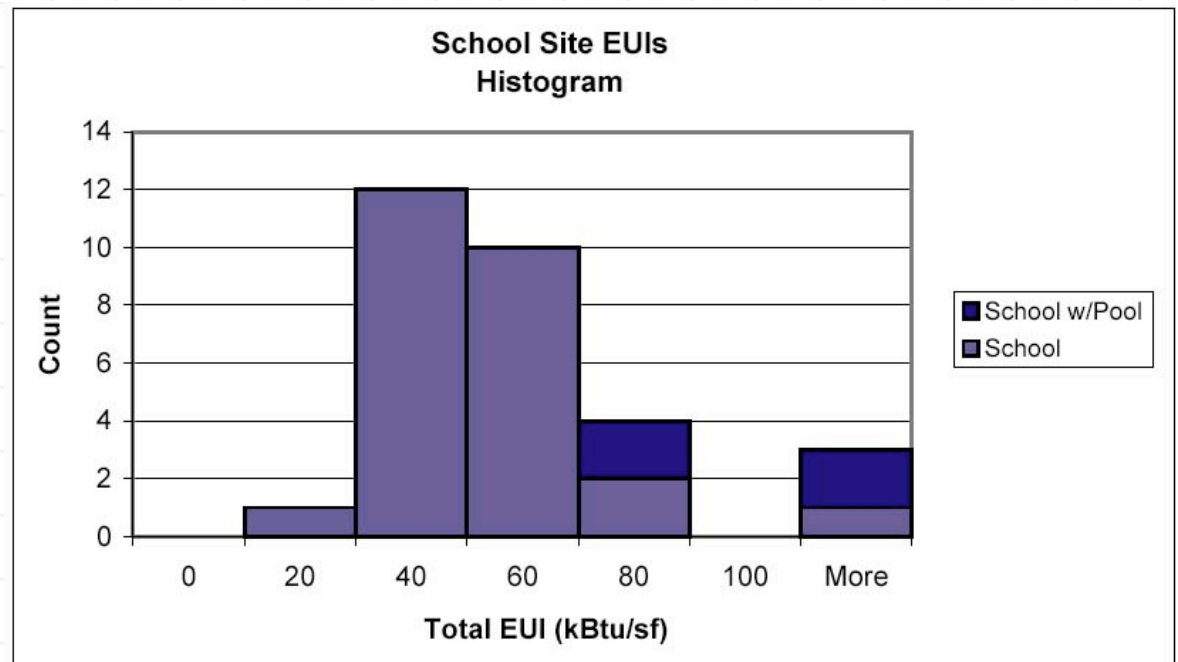
Metrics  
Assessment Records Click this button to view and edit Assessment Records for the Objective selected above.

Index	Metric Name	Metric Description	Target	Units
1	Total annual kWh/sf	Whole-building electric energy use per gross square foot of building. From building electric meter.		
2	Annual source BTU/sf (combined gas and electric)	Whole-building total energy use per gross square foot of building. Source BTU/sf is calculated using XXXX BTU/kWh of electricity and a		

# Caveats & Pitfalls

- ◆ Intensity does not equal efficiency
- ◆ Hard to avoid apples-and-oranges comparisons (want energy per unit of service)
- ◆ Normalization

- v weather
- v floor area
- v schedule
- v plug loads
- v indoor conditions
- v energy price
- v more.....



# Recommendations

- ◆ Decide how benchmark is to be used
  - v Choose type(s) of benchmarks
  - v Define “figures of merit” (metrics)
  - v Be creative -- think of audience
- ◆ Need practical data collection and analysis strategy
- ◆ Recognize and possibly integrate with existing non-energy benchmarking systems
- ◆ Benchmarking is a one-handed clap
  - v A means to an end.... What will be done with the information?

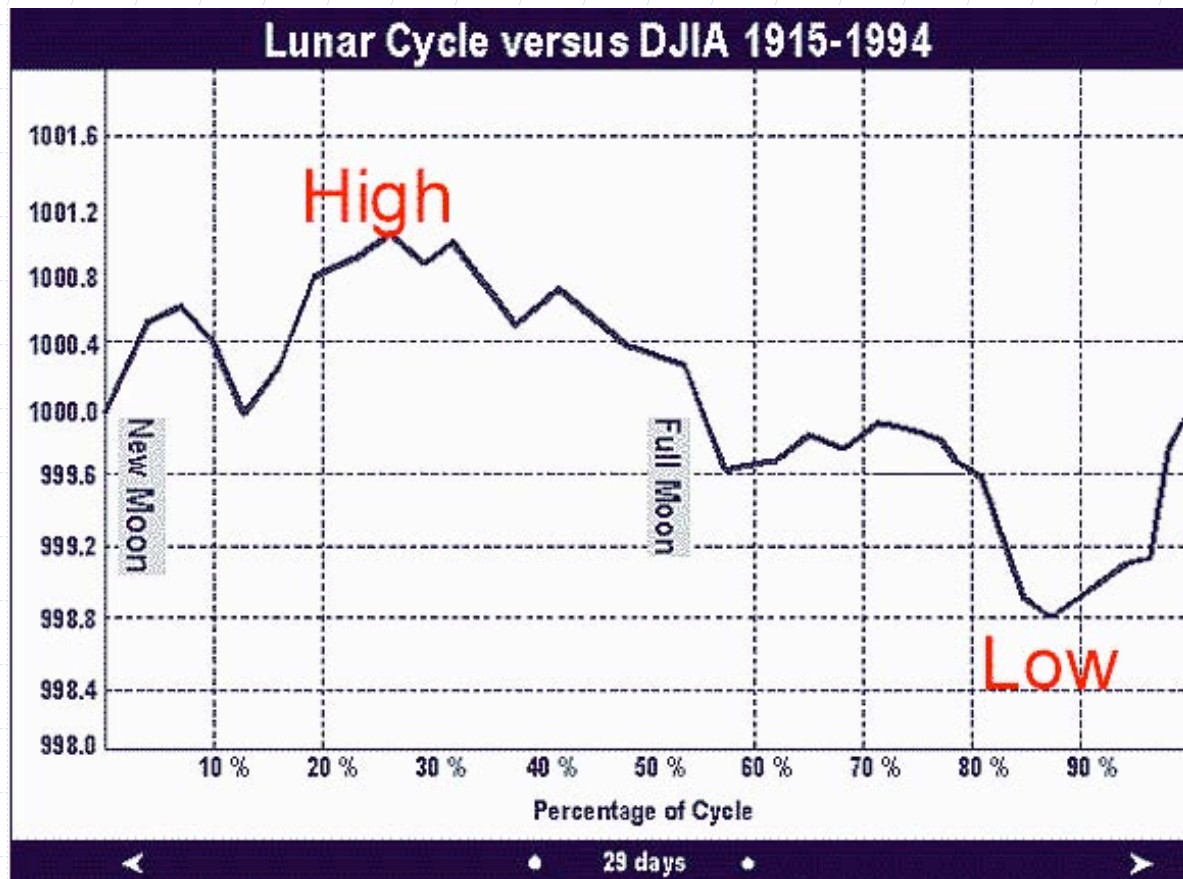


# Moral of the Story

“To define an energy efficiency indicator is not only a technical challenge, but also a pre-structuring of the subsequent policy choice.”

- Aebischer, et al. (2003)

# Correlation is Not Causation!



Advice for Traders: “moon-trading is by no means a stand-alone approach”