# Delivering Energy Proportionality with Non Energy-Proportional Systems – Optimizing the Ensemble

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*Now at VMware



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2006: $4.5 Billion

"The cost of power and cooling is likely to exceed that of hardware…"

- Luiz Barosso, Google

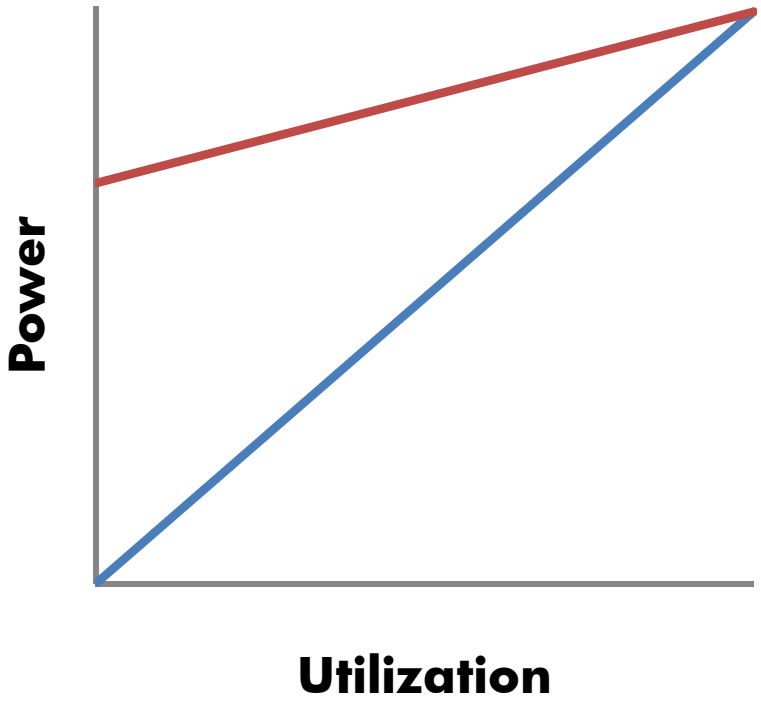
"In the data center, power and cooling costs more than the IT equipment it supports."

- Christian L. Belady, Microsoft

# Energy-Proportional Computing

Consume energy in proportion to the amount of work performed.

[Barosso07]

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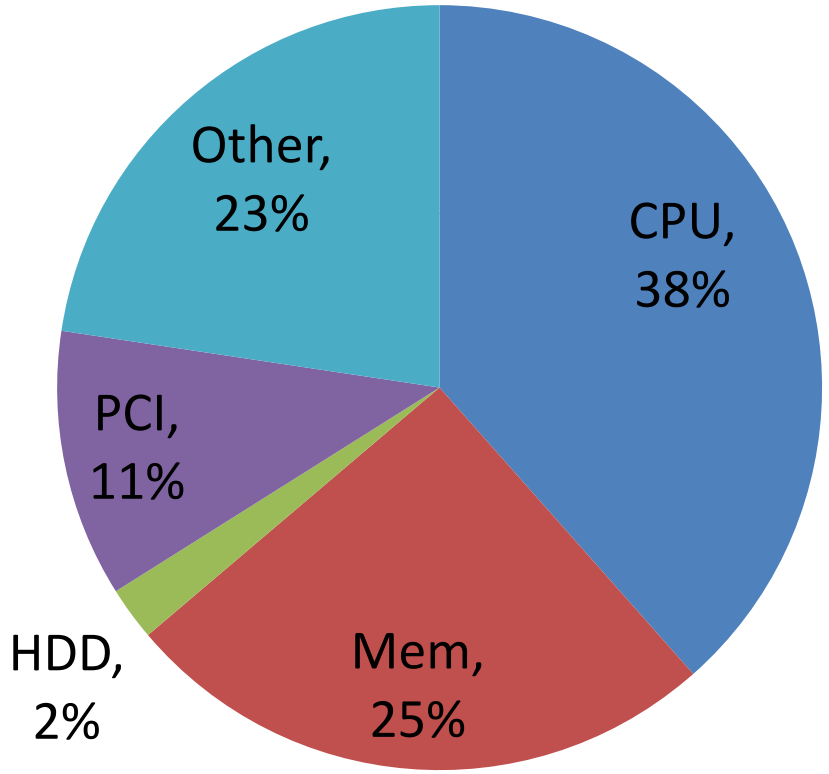
# Energy Proportionality requires "significant improvements in the energy usage profile of every system component"




Power Breakdown for a Busy "Medium" Server

Source: Leigh07, PhD Dissertation

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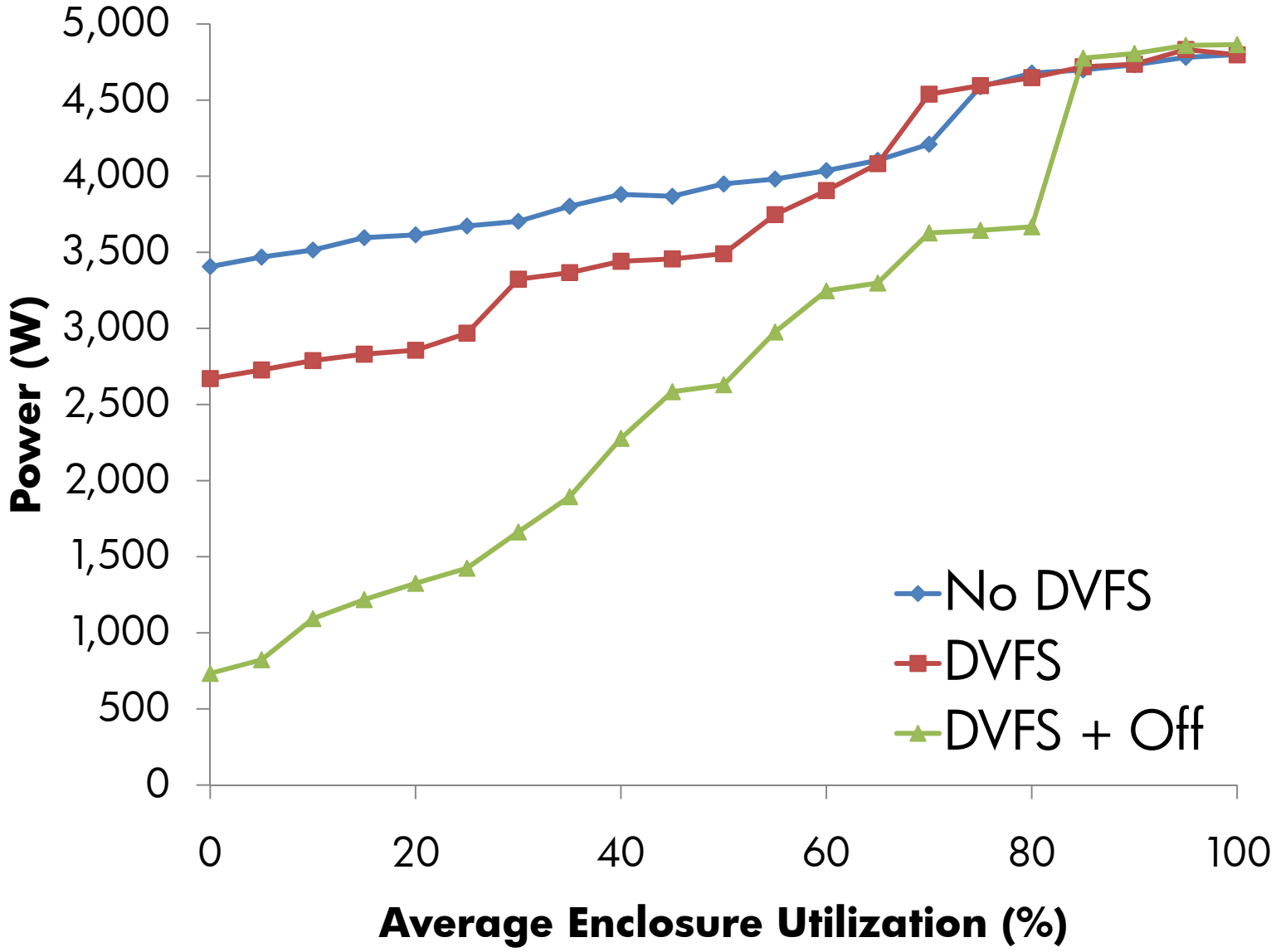
# Use Software to achieve Proportionality

- Leverage multiple servers + virtualization
- Use optimization to make the **ensemble** approximate a theoretical energy-proportional system

- Tradeoff: Software Complexity for Power Savings

# Two Case Studies

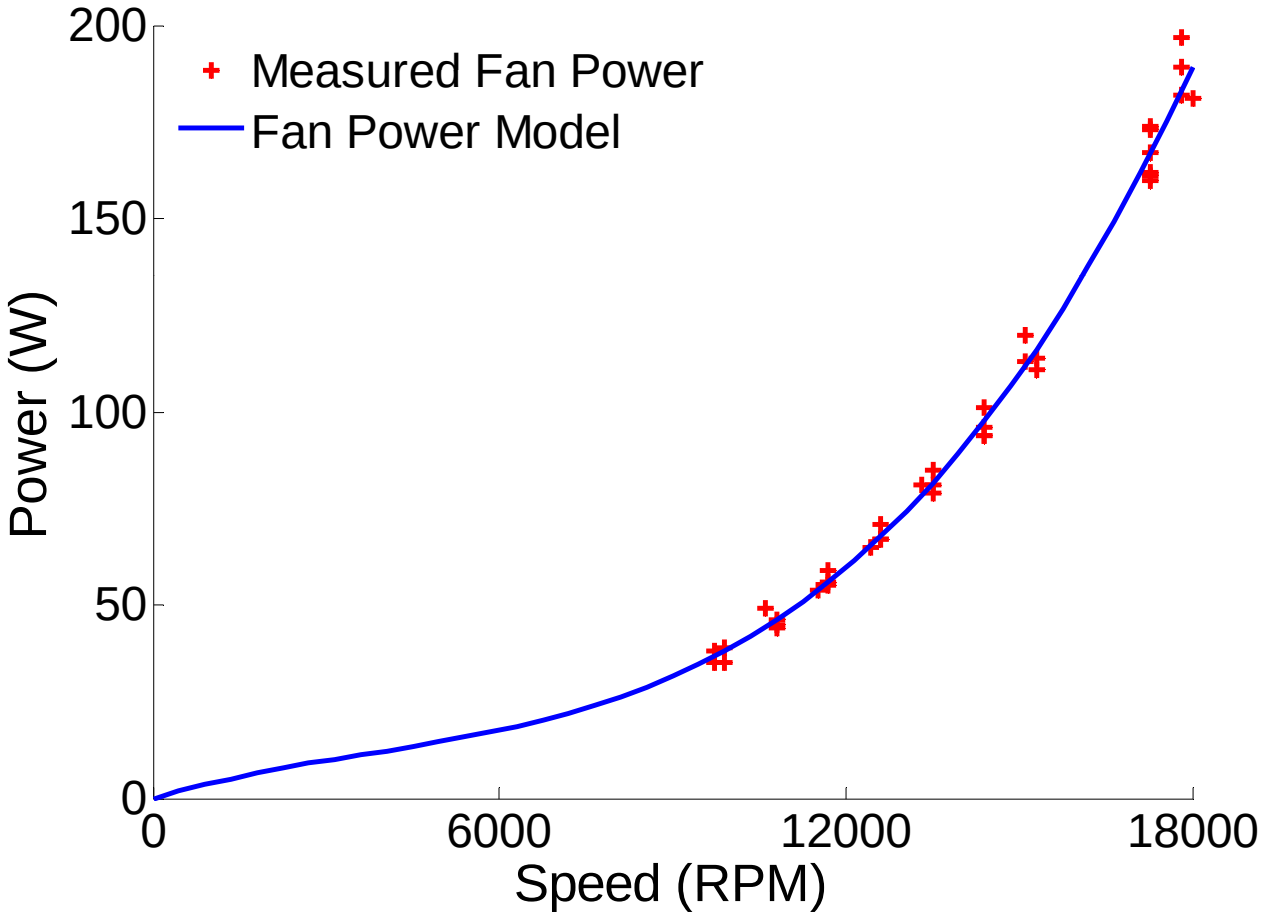
- Ensemble: Blade Enclosure
  - Server Power
  - Cooling Power

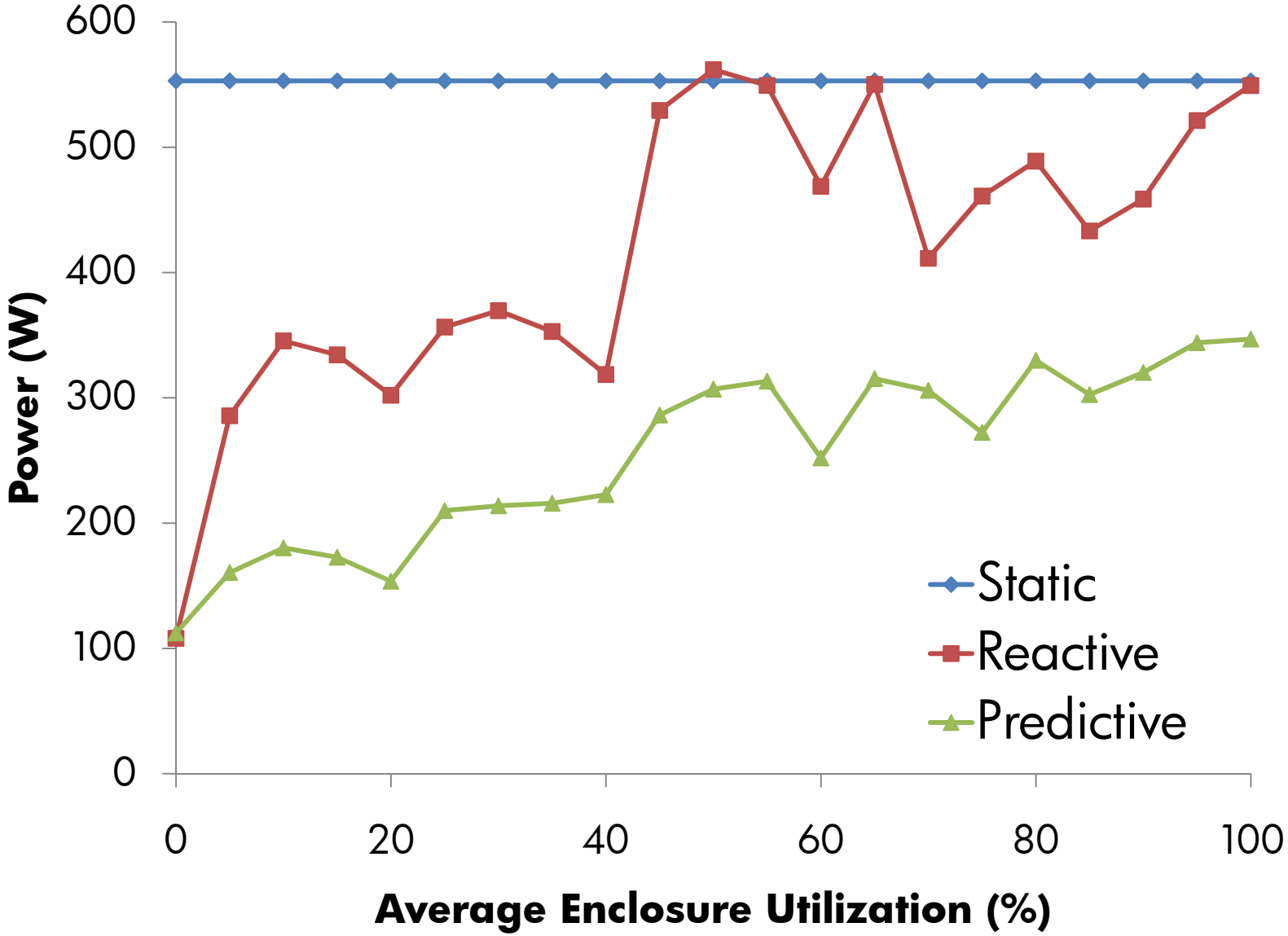

5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Power (W)
0
20
40
60
80
100
Average Enclosure Utilization (%)
No DVFS
DVFS
DVFS + Off

# Two Case Studies

- Ensemble: Blade Enclosure
  - Server Power
  - Cooling Power

# Power Model: Single Fan





600
500
400
300
200
100
0
Power (W)
0
20
40
60
80
100
Average Enclosure Utilization (%)
Static
Reactive
Predictive

# Caveat Emptor

- CPU heterogeneity in data centers
- Locally-attached storage
- Reliability
  - Hardware
  - Applications

# Conclusion

- Treat ensemble as the computational unit
- Optimize to approximate energy proportionality

- Apply to other non-proportional components
  - Network, Storage, CRACs, Power Supplies