# Supercomputers (Titan!), Big Data Analytics, and Energy Efficient Robo-Homes

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Oak Ridge National Laboratory

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ORNL is managed by UT-Battelle
for the US Department of Energy

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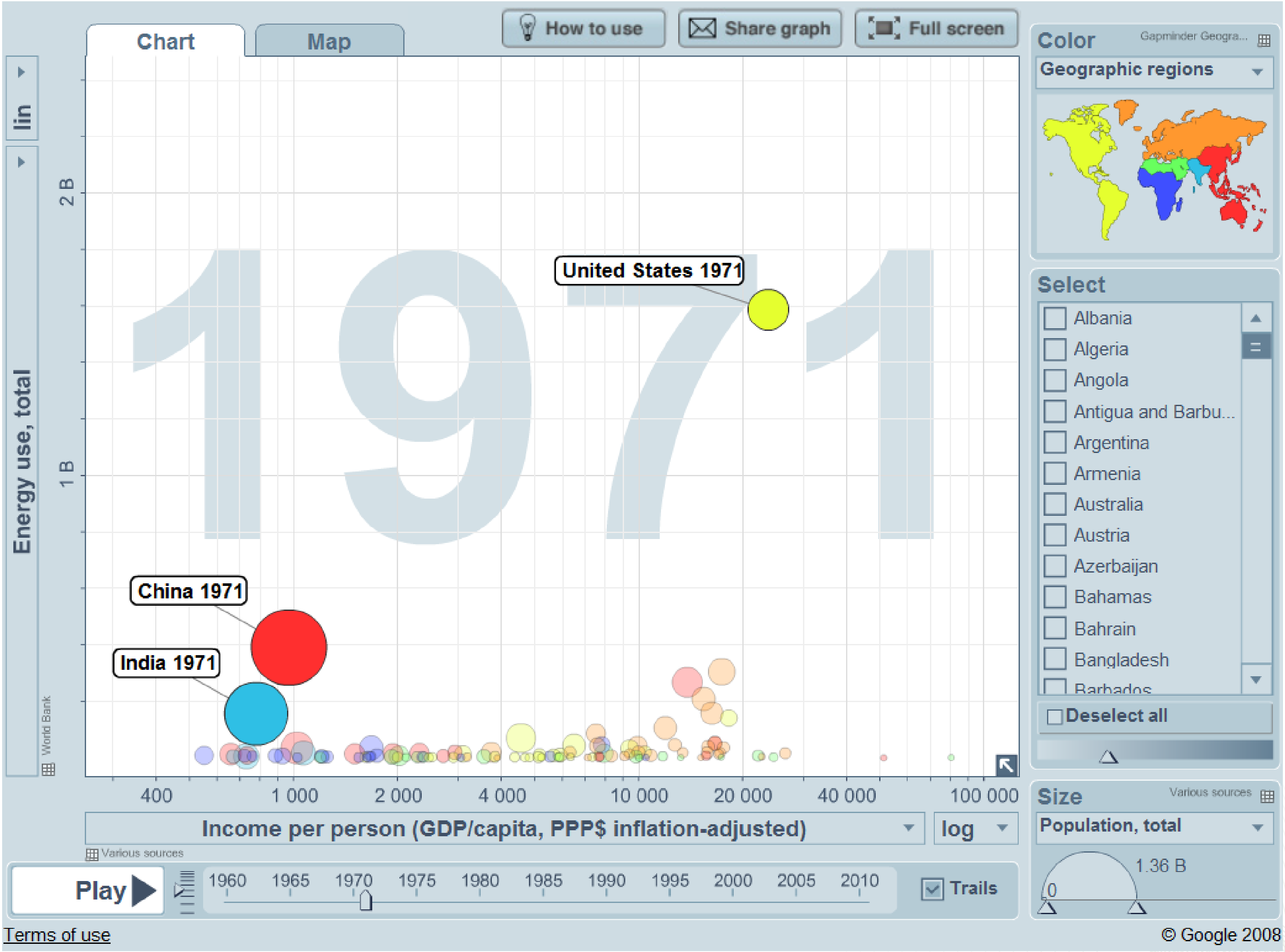
# A brief history of energy and life quality

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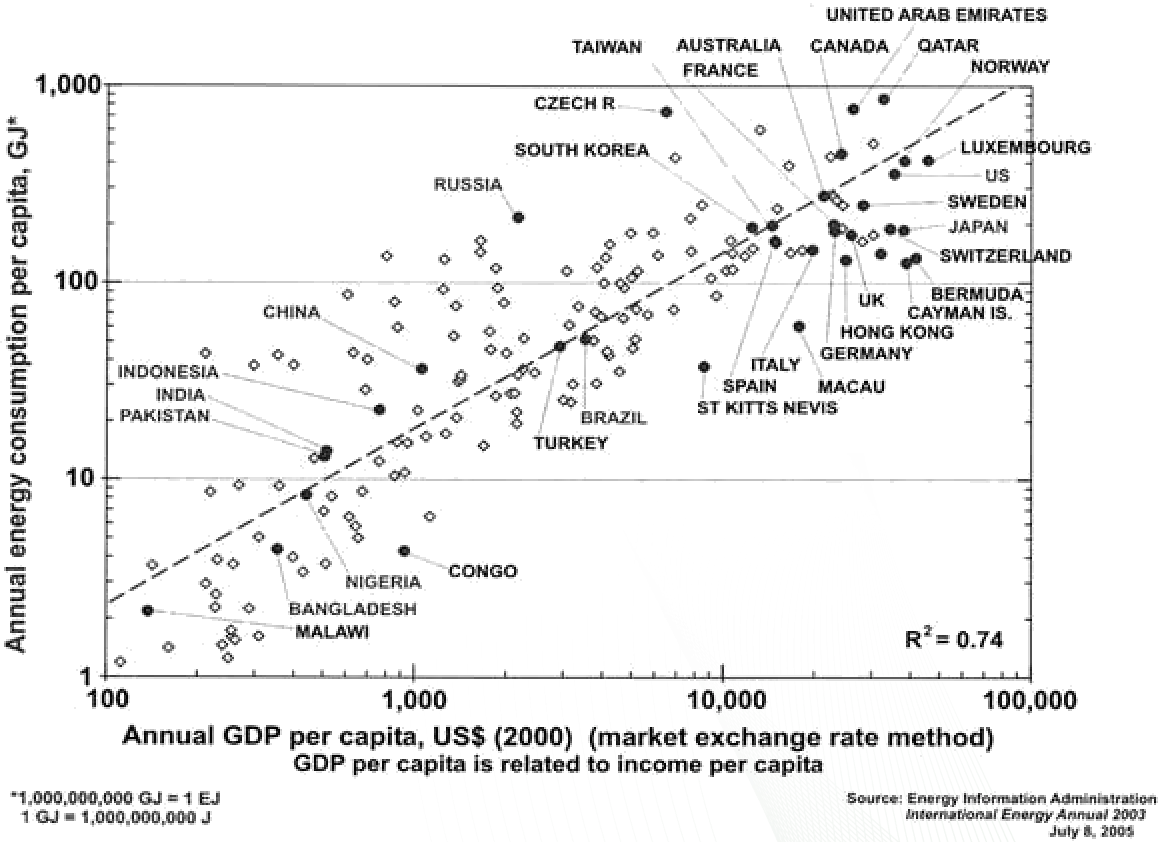
# Sustainability is the defining challenge

- Buildings in U.S.
  - 41% of primary energy/carbon 73% of electricity, 34% of gas
- Buildings in China
  - 60% of urban building floor space in 2030 has yet to be built
- Buildings in India
  - 67% of all building floor space in 2030 has yet to be built

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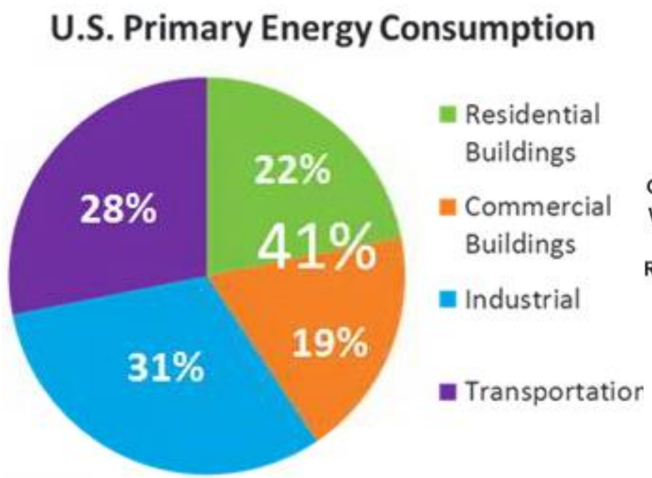
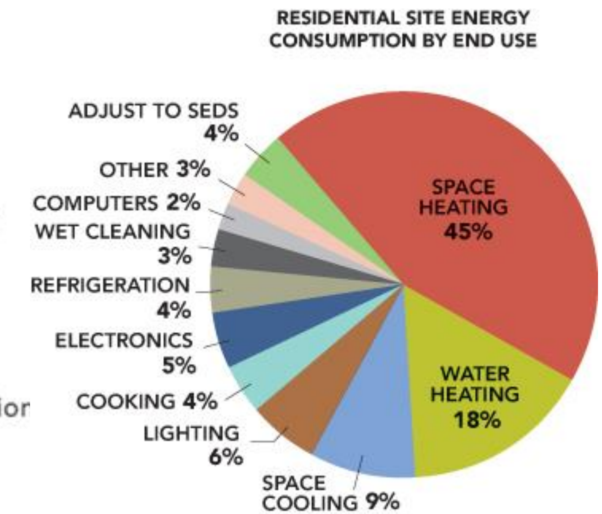
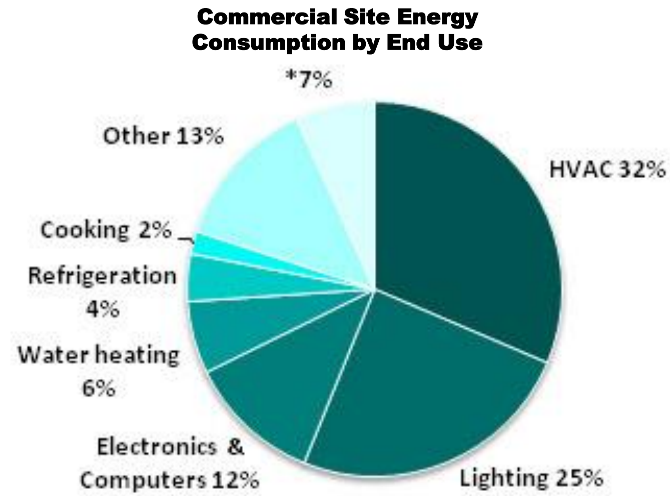
3

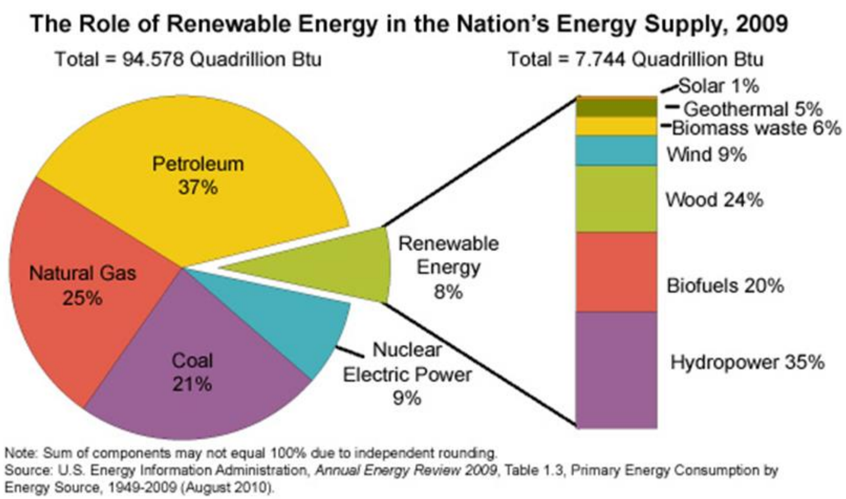
# Energy Consumption and Production

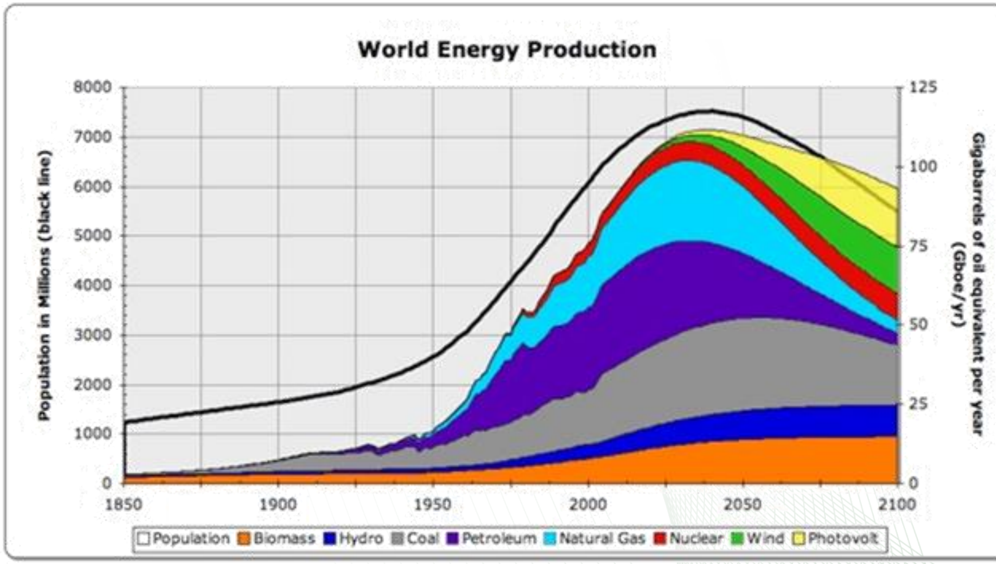



TN 2012 Electric Bill - $1,533



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# Presentation summary

- Scientific Paradigms
- Roof Savings Calculator
- Visual Analytics
- Knowledge Work
- Autotune
- Example Data Tools
- Saving Money

# Presentation summary

- Scientific Paradigms (context)
- Roof Savings Calculator
- Visual Analytics
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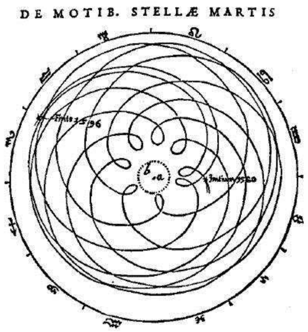
# 4th Paradigm –
## The Science behind the Science

- Empirical – guided by experiment/ observation
  - In use thousands of years ago, natural phenomena
- Theoretical – based on coherent group of principles and theorems
  - In use hundreds of years ago, generalizations
- Computational – simulating complex phenomena
  - In use for decades
- Data exploration (eScience) – unifies all 3
  - Data capture, curation, storage, analysis, and visualization
  - Jim Gray, free PDF from MS Research

Tycho Brahe



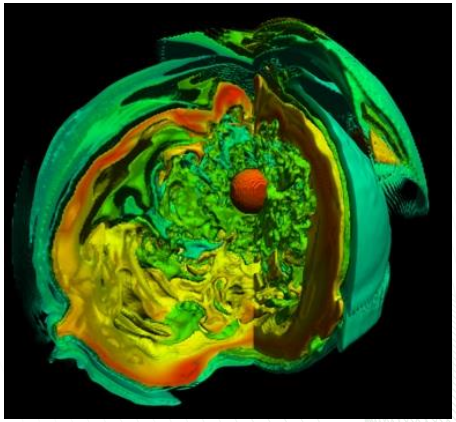

Johannes Kepler

$$\oint \mathbf{E} \cdot d\mathbf{A} = q / \varepsilon_0$$

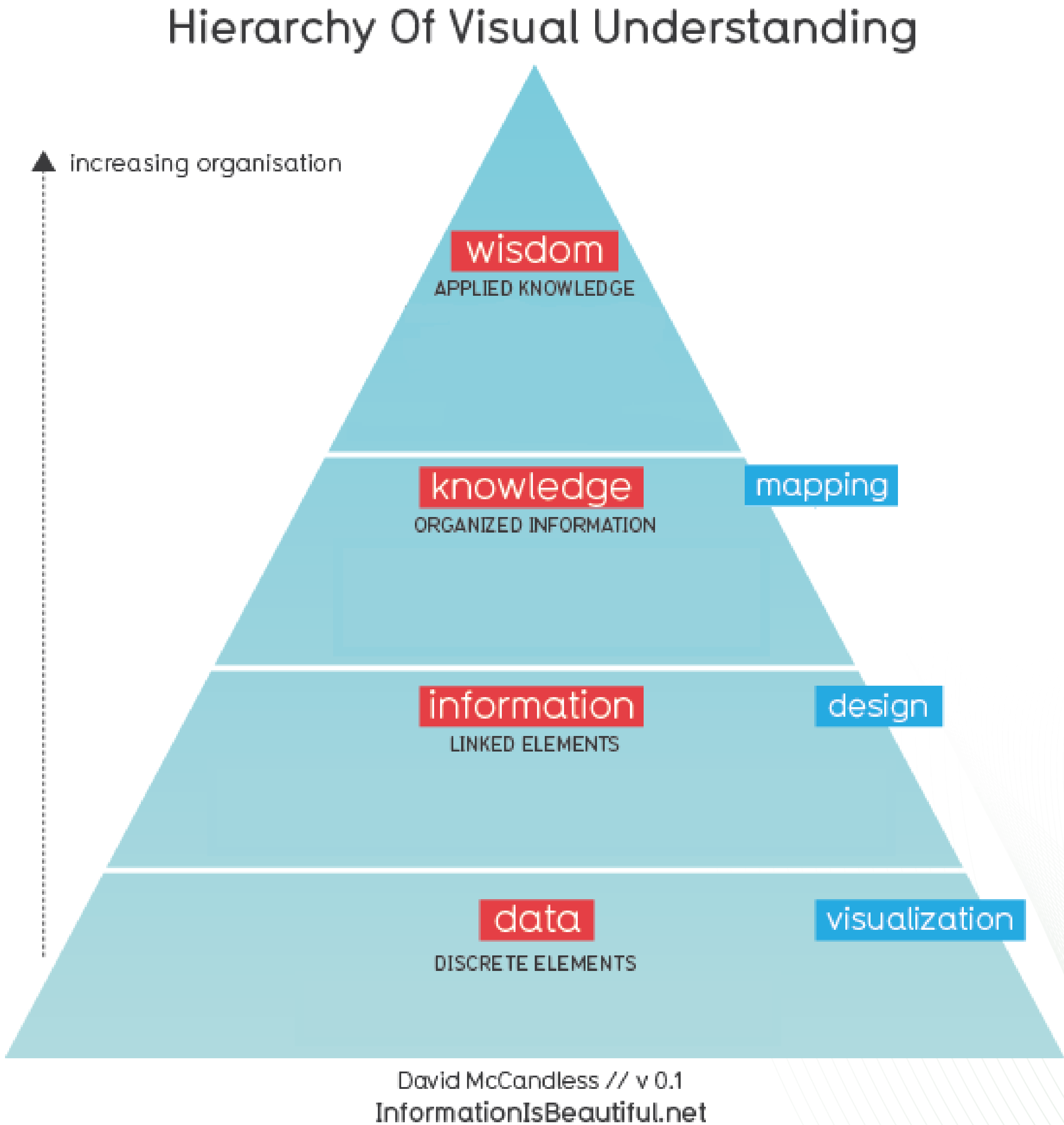
$$\oint \mathbf{B} \cdot d\mathbf{A} = 0$$

$$\oint \mathbf{E} \cdot d\mathbf{S} = -d\Phi_B / dt$$

$$\oint \mathbf{B} \cdot d\mathbf{S} = \mu_0 i + \mu_0 \varepsilon_0 d\Phi_E / dt$$



# 4th Paradigm



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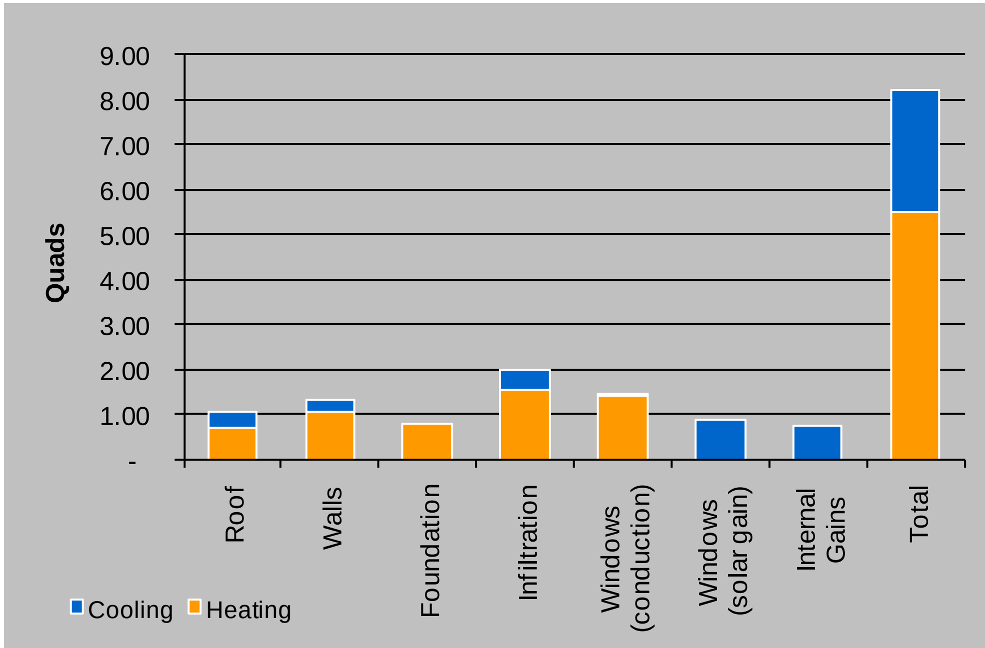



**Figure 2. Residential energy loads attributed to envelope and windows**

***Source: Building Energy Data Book, U.S. DOE, Prepared by D&R International, Ltd., September 2008.***

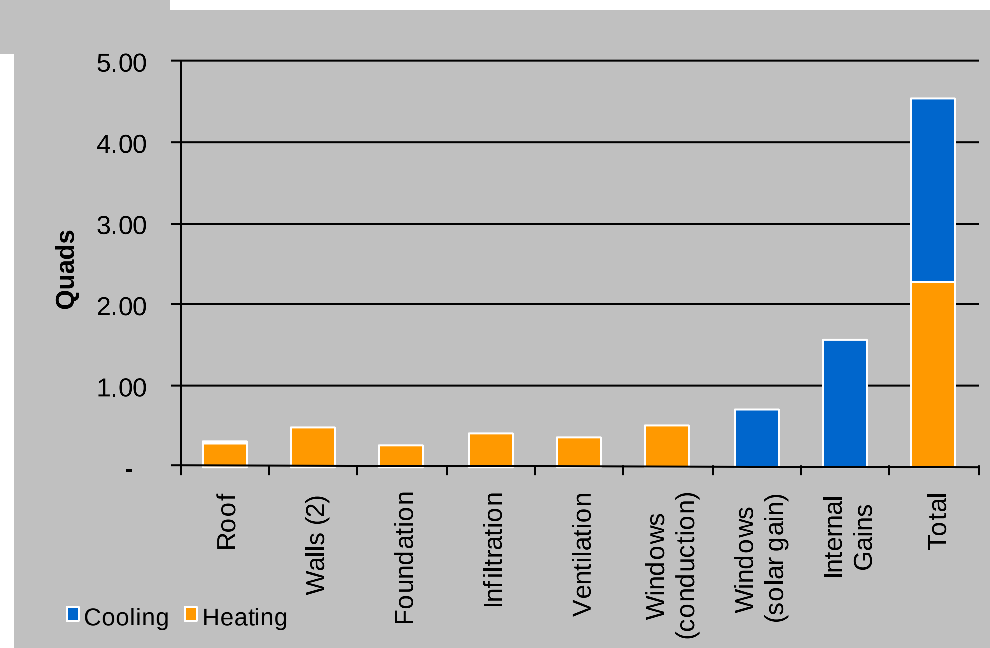



**Figure 3. Commercial energy loads attributed to envelope and windows**

***Source: Building Energy Data Book, U.S. DOE, Prepared by D&R International, Ltd., September 2008.***

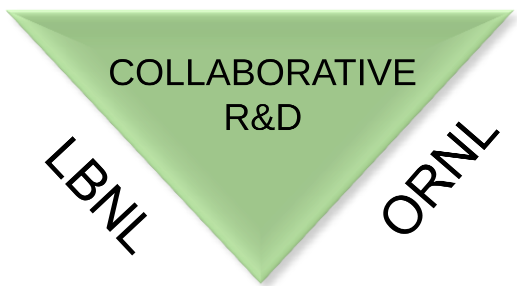
# Computer tools for simulating cool roofs

## Roof Savings Calculator (RSC)

Chris Scruton
CEC

INDUSTRY

Marc LaFrance
DOE BT




R. Levinson,
H. Gilbert,
H. Akbari

A. Desjarlais,
W. Miller,
J. New

WBT

Joe Huang,
Ender Erdem



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# Roof Savings Calculator

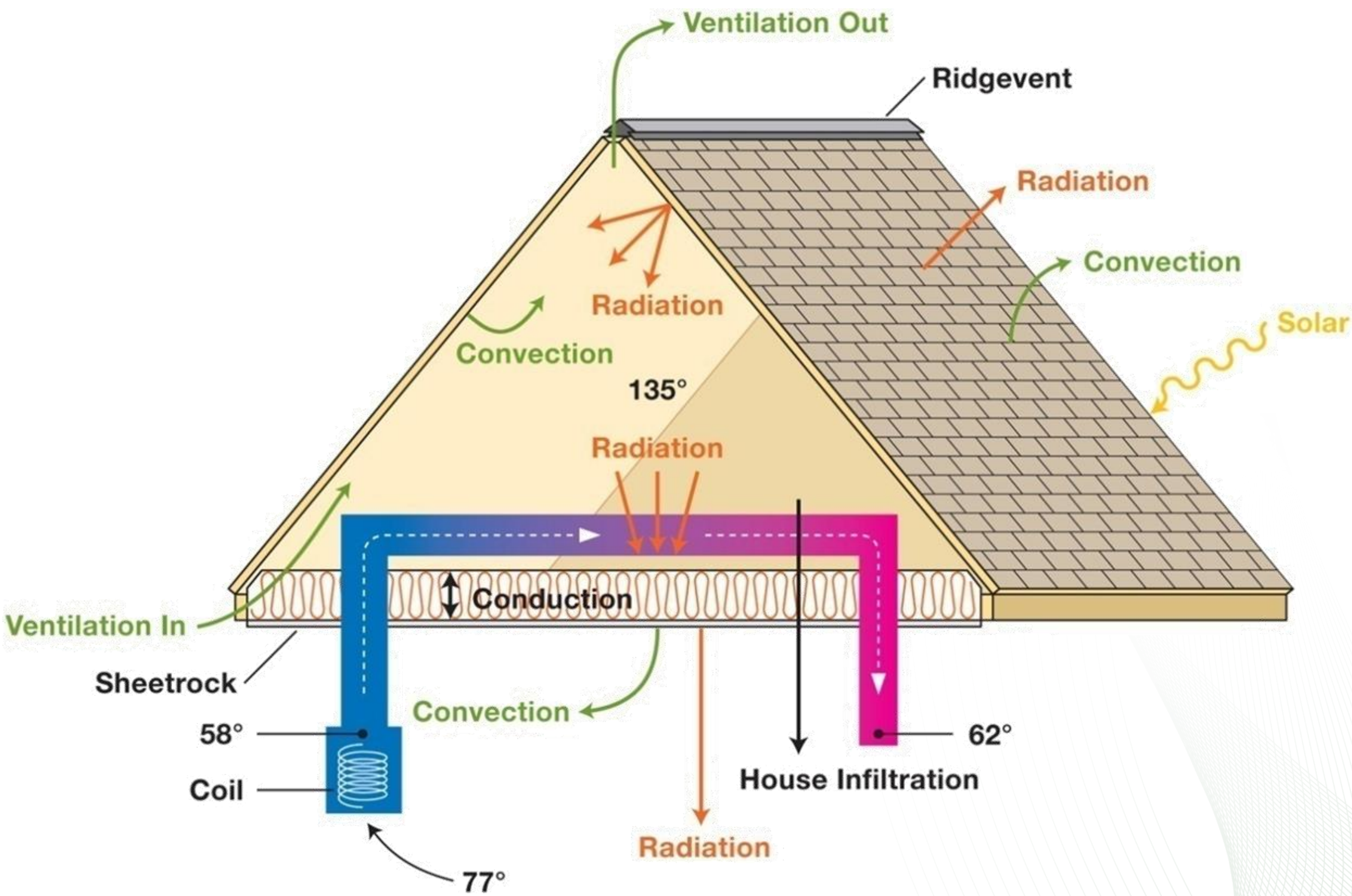
- Replaces:
  - EPA Roof Comparison Calc
  - DOE Cool Roof Calculator
- Minimal questions (<20)
  - Only location is required
  - Building America defaults
  - Help links for unknown information

## Calculator Input Comparison Chart

| | RSC[1] | PAC Slides[2] | PAC QRpt[3] | EPA[4] | DOE[5] |
|---|---|---|---|---|---|
| Building Type | ✓ | ✓ | ✓ | ✓ | |
| Location | ✓ | ✓ | | ✓ | ✓ |
| Days of Operation per week | | ✓ | ✓ | ✓ | |
| Building stock | ✓ | ✓ | | ✓ | |
| Cooling system efficiency (SEER) | ✓ | ✓ | ✓ | ✓ | ✓ |
| Type of heating | ✓ | ✓ | ✓ | ✓ | ✓ |
| Heating system efficiency | ✓ | ✓ | ✓ | ✓ | ✓ |
| Duct location | ✓ | ✓ | ✓ | | |
| Level of roof/ceiling insulation | ✓ | ✓ | ✓ | ✓ | ✓ |
| Above-sheathing ventilation | ✓ | ✓ | | | |
| Radiant barrier | ✓ | ✓ | | | |
| Roof thermal mass | ✓ | ✓ | | | |
| Roof solar reflectance | ✓ | ✓ | ✓ | ✓ | ✓ |
| Roof solar reflectance (black compare) | ✓ | | ✓ | ✓ | |
| Roof thermal emittance | ✓ | ✓ | ✓ | | ✓ |
| Roof thermal emittance (black compare) | ✓ | | ✓ | | |
| Internal load | | ✓ | | | |
| Conditioned space under roof | | ✓ | | | |
| Gas and electricity costs | ✓ | ✓ | ✓ | ✓ | ✓ |
| Inclination / Roof Area | ✓ | | | ✓ | |
| HVAC Schedule | | | ✓ | | |
| Conditioned space ($ft^2$) | ✓ | | | ✓ | |
| Number of floors | ✓ | | | | |
| Window-to-wall ratio | ✓ | | | | |

# RSC = AtticSim + DOE-2.1E

**AtticSim - ASTM C 1340 Standard For Estimating Heat Gain or Loss Through Ceilings Under Attics**



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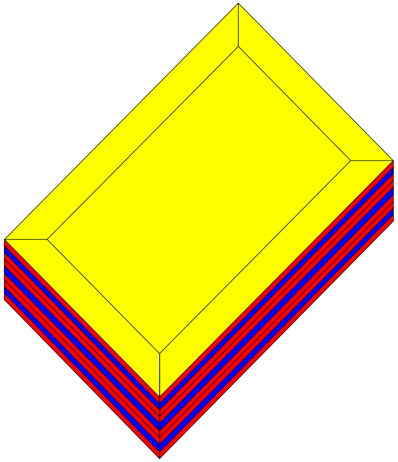
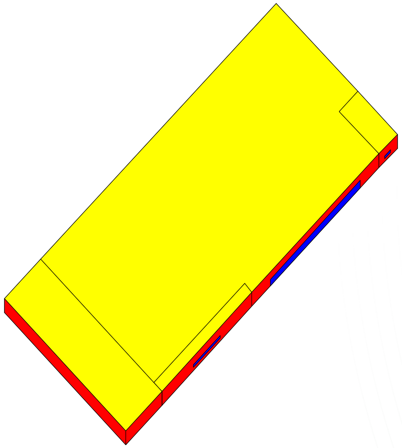
# Commercial building types

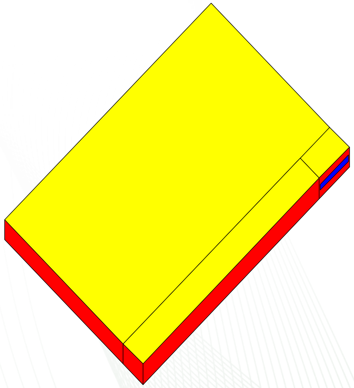
Office



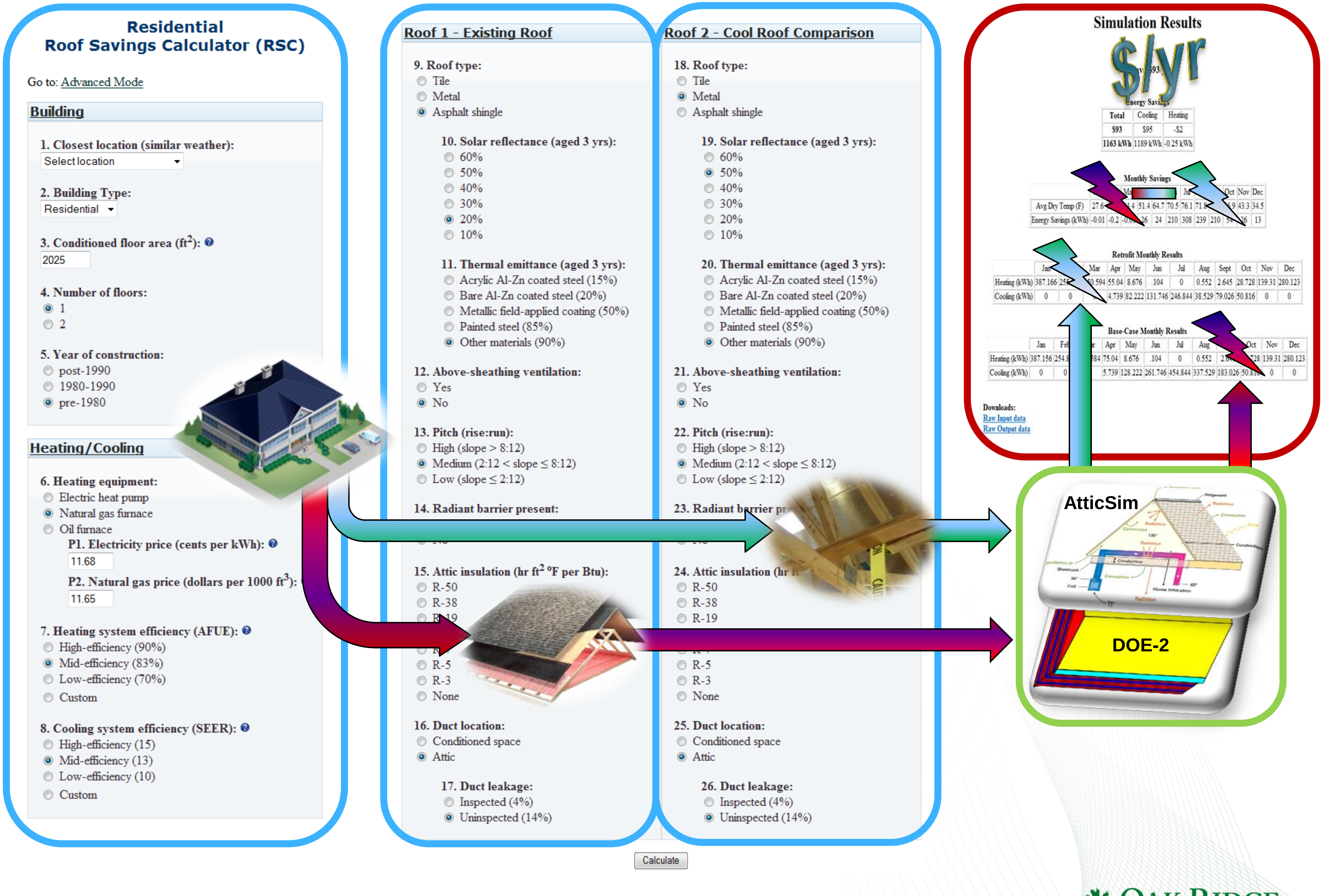
"Big Box" Retail

Warehouse



Torcellini et al. 2008, "DOE Commercial Building Benchmark Models", NREL/CP-550-43291, National Renewable Energy Laboratory, Golden CO.


Residential
Roof Savings Calculator (RSC)
Go to: Advanced Mode
Building
1. Closest location (similar weather):
Select location
2. Building Type:
Residential
3. Conditioned floor area (ft2):
2025
4. Number of floors:
1
2
5. Year of construction:
post-1990
1980-1990
pre-1980
Heating/Cooling
6. Heating equipment:
Electric heat pump
Natural gas furnace
Oil furnace
P1. Electricity price (cents per kWh):
11.68
P2. Natural gas price (dollars per 1000 ft3):
11.65
7. Heating system efficiency (AFUE):
High-efficiency (90%)
Mid-efficiency (83%)
Low-efficiency (70%)
Custom
8. Cooling system efficiency (SEER):
High-efficiency (15)
Mid-efficiency (13)
Low-efficiency (10)
Custom
Roof 1 - Existing Roof
9. Roof type:
Tile
Metal
Asphalt shingle
10. Solar reflectance (aged 3 yrs):
60%
50%
40%
30%
20%
10%
11. Thermal emittance (aged 3 yrs):
Acrylic Al-Zn coated steel (15%)
Bare Al-Zn coated steel (20%)
Metallic field-applied coating (50%)
Painted steel (85%)
Other materials (90%)
12. Above-sheathing ventilation:
Yes
No
13. Pitch (rise:run):
High (slope > 8:12)
Medium (2:12 < slope ≤ 8:12)
Low (slope ≤ 2:12)
14. Radiant barrier present:
15. Attic insulation (hr ft2 °F per Btu):
R-50
R-38
R-5
R-3
None
16. Duct location:
Conditioned space
Attic
17. Duct leakage:
Inspected (4%)
Uninspected (14%)
Roof 2 - Cool Roof Comparison
18. Roof type:
Tile
Metal
Asphalt shingle
19. Solar reflectance (aged 3 yrs):
60%
50%
40%
30%
20%
10%
20. Thermal emittance (aged 3 yrs):
Acrylic Al-Zn coated steel (15%)
Bare Al-Zn coated steel (20%)
Metallic field-applied coating (50%)
Painted steel (85%)
Other materials (90%)
21. Above-sheathing ventilation:
Yes
No
22. Pitch (rise:run):
High (slope > 8:12)
Medium (2:12 < slope ≤ 8:12)
Low (slope ≤ 2:12)
23. Radiant barrier pr
24. Attic insulation (hr ft
R-50
R-38
R-19
R-5
R-3
None
25. Duct location:
Conditioned space
Attic
26. Duct leakage:
Inspected (4%)
Uninspected (14%)
Calculate
Simulation Results
$/yr
Monthly Savings
Retrofit Monthly Results
Base-Case Monthly Results
Downloads:
Raw Input data
Raw Output data
AtticSim
DOE-2

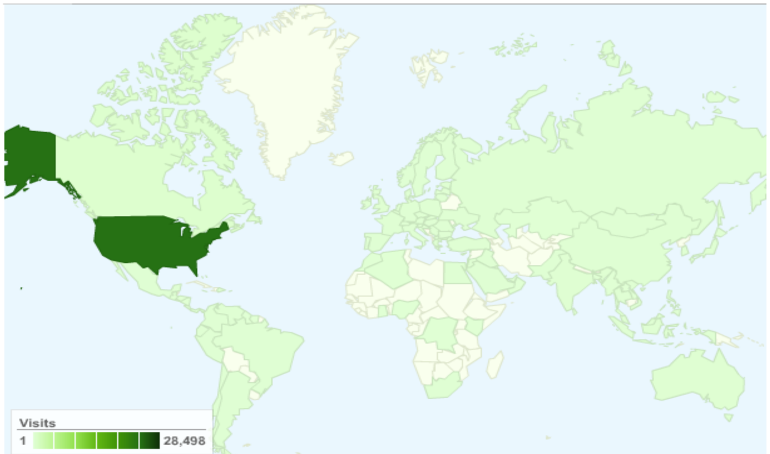
# RoofCalc.com impact

**Dashboard**

Apr 20, 2010 - Feb 28, 2011

**100,000+ visitors, 200+ user feedback,**

**Average: ~81 visitors/day**

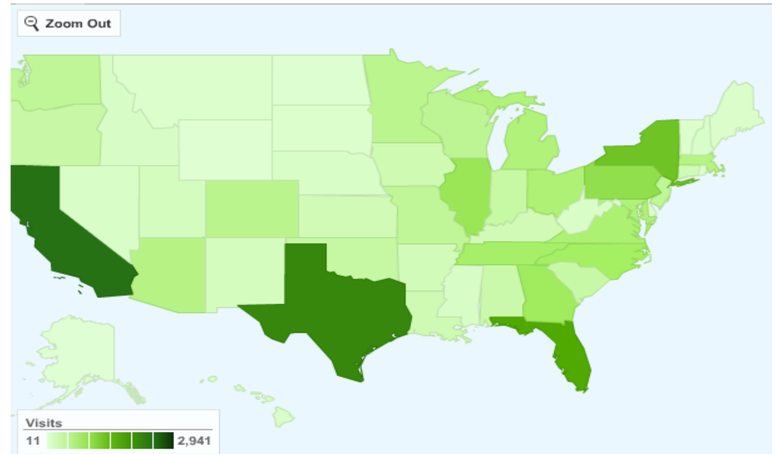

**30,752 visits came from 112 countries/territories**

Detail Level: City | Country/Territory | Sub Continent Region | Continent   Dimension: None

Site Usage | Goal Set 1

| Visits | Pages/Visit | Avg. Time on Site | % New Visits | Bounce Rate |
|---|---|---|---|---|
| 30,752<br>% of Site Total: 100.00% | 1.42<br>Site Avg: 1.42 (0.00%) | 00:01:25<br>Site Avg: 00:01:25 (0.00%) | 88.26%<br>Site Avg: 88.23% (0.04%) | 70.34%<br>Site Avg: 70.34% (0.00%) |

| | Detail Level: Country/Territory | Visits | Pages/Visit | Avg. Time on Site | % New Visits | Bounce Rate |
|---|---|---|---|---|---|---|
| 1. | United States | 28,498 | 1.42 | 00:01:25 | 88.35% | 70.34% |
| 2. | Canada | 483 | 1.36 | 00:01:05 | 91.30% | 73.08% |
| 3. | India | 156 | 1.42 | 00:01:08 | 80.77% | 73.72% |
| 4. | Australia | 129 | 1.66 | 00:01:42 | 82.17% | 66.67% |
| 5. | United Kingdom | 94 | 1.39 | 00:01:13 | 94.68% | 65.96% |
| 6. | South Korea | 79 | 1.52 | 00:01:07 | 70.89% | 68.35% |
| 7. | Italy | 66 | 1.61 | 00:01:33 | 89.39% | 63.64% |




**This country/territory sent 28,498 visits via 52 regions**

Detail Level: City | Region   Dimension: None

Site Usage | Goal Set 1

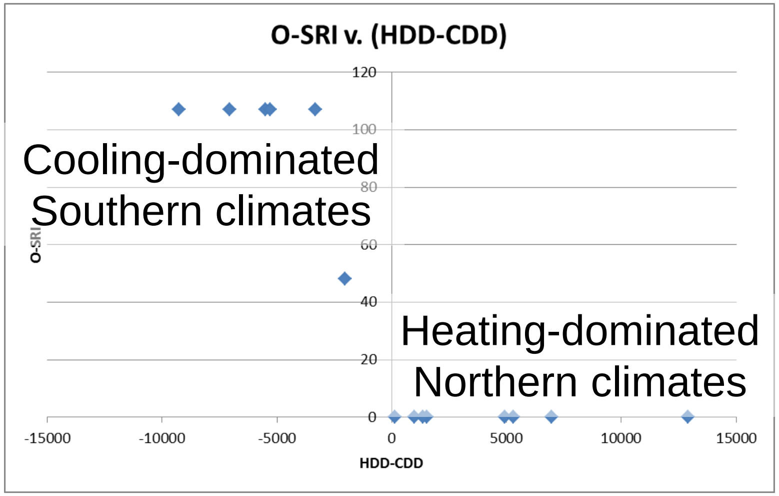
| Visits | Pages/Visit | Avg. Time on Site | % New Visits | Bounce Rate |
|---|---|---|---|---|
| 28,498<br>% of Site Total: 92.67% | 1.42<br>Site Avg: 1.42 (-0.09%) | 00:01:25<br>Site Avg: 00:01:25 (0.96%) | 88.35%<br>Site Avg: 88.23% (0.14%) | 70.34%<br>Site Avg: 70.34% (-0.00%) |

| | Detail Level: Region | Visits | Pages/Visit | Avg. Time on Site | % New Visits | Bounce Rate |
|---|---|---|---|---|---|---|
| 1. | California | 2,941 | 1.37 | 00:01:21 | 82.66% | 73.95% |
| 2. | Texas | 2,558 | 1.43 | 00:01:26 | 90.30% | 68.22% |
| 3. | Florida | 1,965 | 1.47 | 00:01:43 | 89.52% | 68.09% |
| 4. | New York | 1,608 | 1.35 | 00:01:09 | 91.42% | 73.45% |
| 5. | Pennsylvania | 1,206 | 1.39 | 00:01:20 | 91.04% | 71.72% |
| 6. | Illinois | 1,114 | 1.36 | 00:01:12 | 89.41% | 73.79% |
| 7. | Georgia | 1,032 | 1.40 | 00:01:18 | 90.50% | 69.09% |

# Nationwide results

Cost savings for offices - 14 cities, local utility prices, 22 roof types

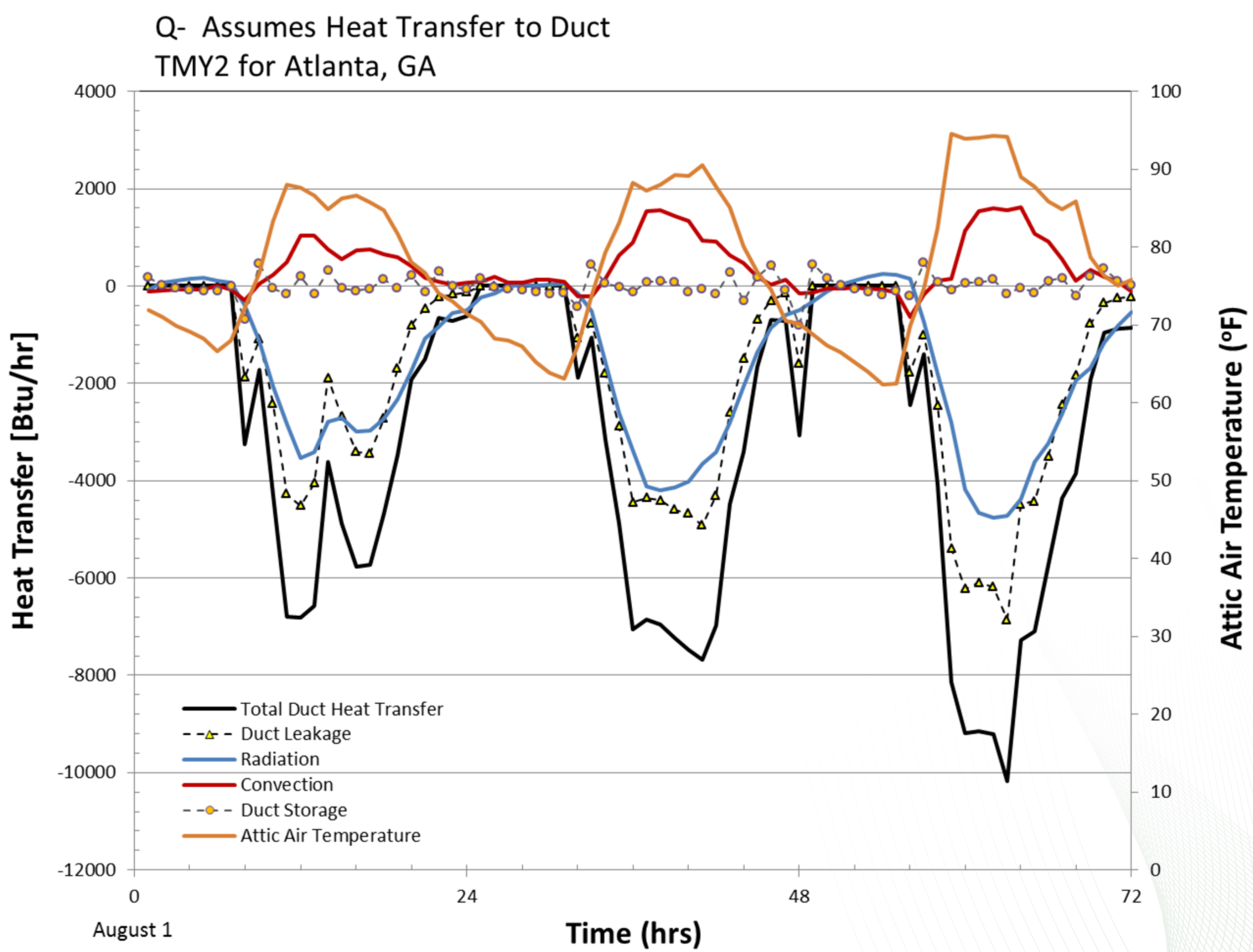
| Description | Reflectance | Emissivity | SRI | Houston $ saved | …13 |
|---|---|---|---|---|---|
| BUR No Coating | 10 | 90 | 6 | 42 | |
| Mineral Mod Bit | 25 | 88 | 25 | 103 | |
| Single Ply | 32 | 90 | 35 | 230 | |
| Mineral Mod Bit | 33 | 92 | 35 | 197 | |
| Metal | 35 | 82 | 35 | 60 | |
| Aluminum Coating | 43 | 58 | 35 | 279 | |
| Mineral Mod Bit | 45 | 79 | 55 | 291 | |
| Coating over BUR | 49 | 83 | 55 | 433 | |
| Metal | 49 | 83 | 55 | 208 | |
| …14 | | | | | |




| Location | Trend Desired SRI | Maximum Observed Savings, $ | Best Observed System | Related SRI | Slope Difference |
|---|---|---|---|---|---|
| Atlanta | 107 | 1080 | Aluminum Coating over BUR | 65 | Reversed |
| Austin | 107 | 2680 | Coating over BUR (White) | 107 | Same |
| Baltimore | 107 | 1000 | Single Ply /Coating over BUR | 103.5 | Reversed |
| Chicago | 64.95 | 360 | Aluminum Coating over BUR | 48 | Same |
| Fairbanks | 42.68 | 680 | Aluminum Coating over BUR | 48 | Same |
| Fargo | 40.58 | 160 | Aluminum Coating over BUR | 48 | Same |
| Houston | 107 | 1840 | Coating over BUR (White) | 107 | Same |
| Kansas City | 107 | 800 | Coating over BUR (White) | 107 | Reversed |
| Los Angeles | 107 | 440 | Aluminum Coating over BUR | 65 | Same |
| Miami | 107 | 4440 | Coating over BUR (White) | 107 | Same |
| Minneapolis | 47.05 | 360 | Aluminum Coating over BUR | 48 | Same |
| New York | 107 | 560 | Aluminum Coating over BUR | 65 | Reversed |
| Phoenix | 107 | 3000 | Coating over BUR (White) | 107 | Same |
| San Francisco | 39.31 | 200 | Aluminum Coating over BUR | 48 | Same |

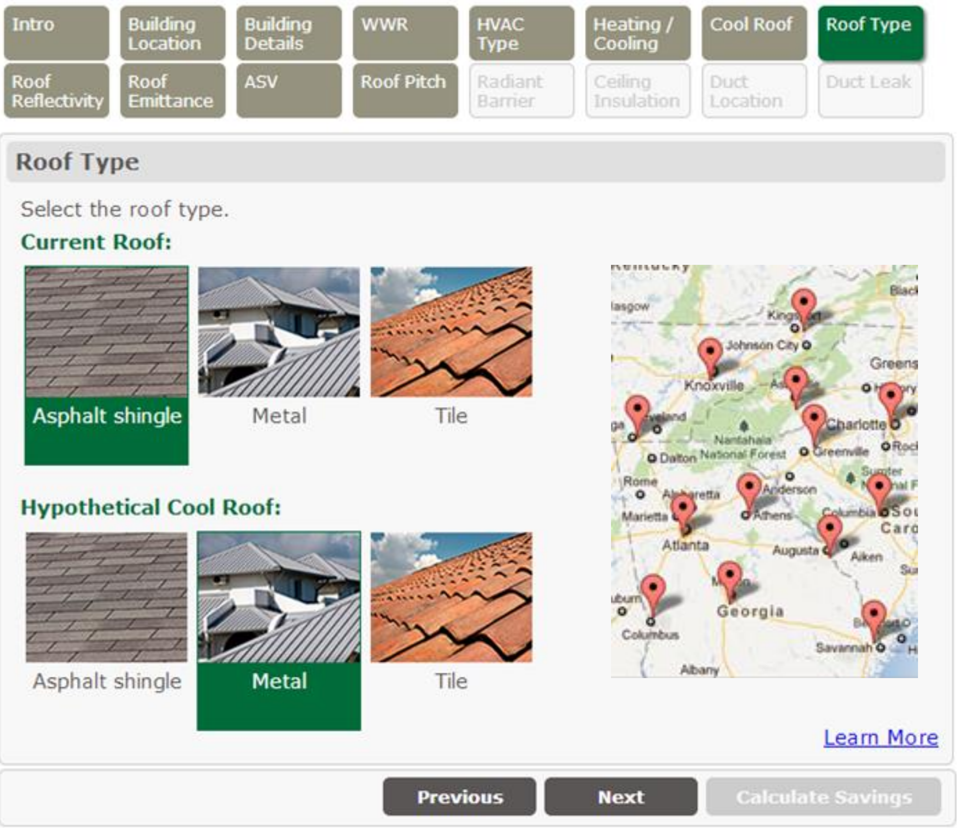
Mellot, Joseph W., New, Joshua R., and Sanyal, Jibonananda. (2013). "Preliminary Analysis of Energy Consumption for Cool Roofing Measures." In *RCI Interface Technical Journal*, volume 31, issue 9, pp. 25-36, October, 2013.

# Summer operation of HVAC duct in ASHRAE climate zone 3

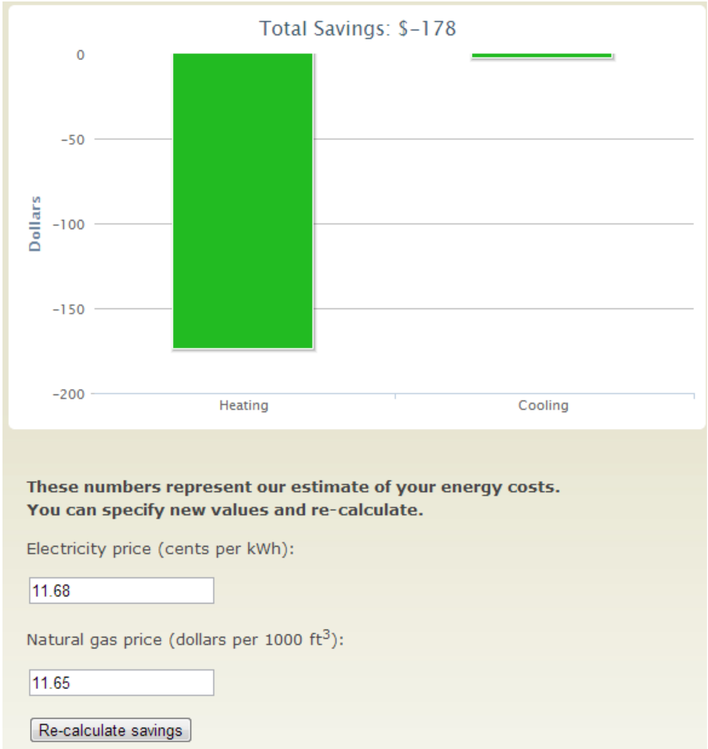


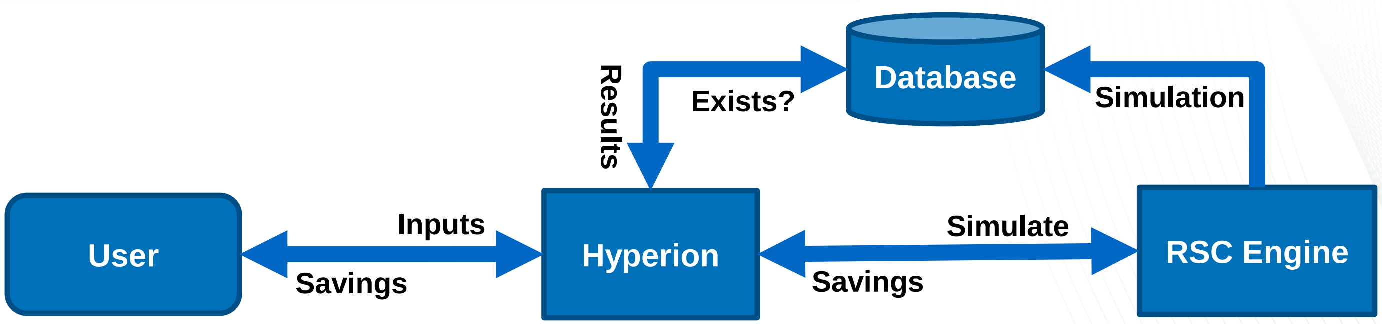
# Enhanced RSC Site

## Input Parameter GUI




## Result Output

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# Quote

**“We speak piously of … making small studies that will add another brick to the temple of science. Most such bricks just lie around the brickyard.”**

**–J.R. Platt, Science 1964, 146:347-53**

# RSC Service Example (Python)

```
client = suds.client.Client('URL/TO/WEB/SERVICE/rsc.wsdl')
print(client)

sm = client.factory.create('schema:soapmodel')
load_soap_model_from_xml('../examplemodel.xml', sm)
sr = client.service.simulate(sm)
print(sr)

sm = client.factory.create('schema:soapmodel')
load_soap_model_from_xml('../examplemodel.xml', sm)
print(sm)
contents = client.service.test(sm)
with open('pytest.zip', 'wb') as outfile:
    outfile.write(base64.b64decode(contents))
```

**…download example building and batch script from rsc.ornl.gov/web-service.shtml**

# Update 1 line of code to change servers

```
import base64
import suds
import xml.dom.minidom
import logging


def load_soap_model_from_xml(xmlfilename, soapmodel):

def load_soap_results_from_xml(xmlfilename, soapresults):


logging.basicConfig()

test_type = ['simulate', 'test', 'upload', 'download']

print ("hello there, initializing client")
client = suds.client.Client('http://evenstar.ornl.gov/RSC/service/rsc.wsdl')
print ("printing client")
print(client)
raw_input('Press Enter to continue...'+'\n')
```

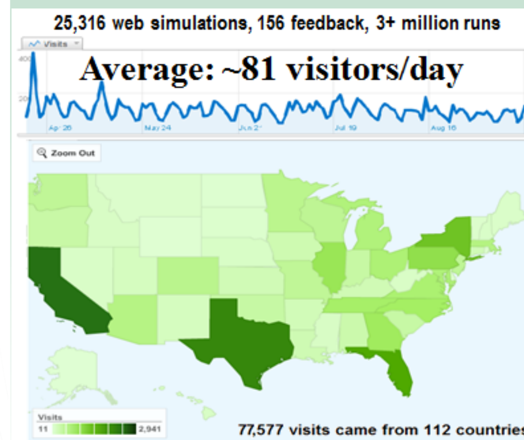
# Millions of simulations visualized for DOE's Roof Savings Calculator and deployment of roof and attic technologies through leading industry partners

**DOE: Office of Science** → **CEC & DOE EERE: BTO** → **Industry & Building Owners**

Engine (AtticSim/DOE-2) debugged using HPC Science assets enabling visual analytics on $3x(10)^6$ simulations


Roof Savings Calculator (RSC) web site/service developed and validated [estimates energy and cost savings from roof and attic technologies]

CentiMark, the largest nation-wide roofing contractor (installs 2500 roofs/mo), is integrating RSC into their proposal generating system (20+ companies now interested)




*Leveraging HPC resources to facilitate deployment of building energy efficiency technologies*



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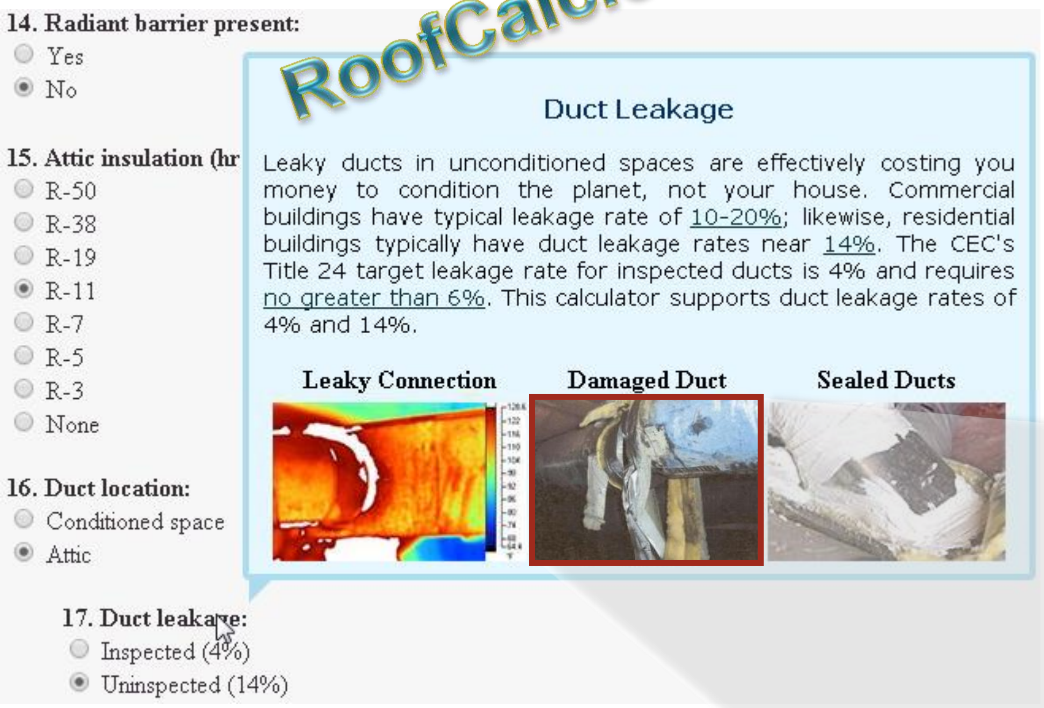
# Personal story behind one of DOE's RSC images

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- Autotune
- Example Data Tools
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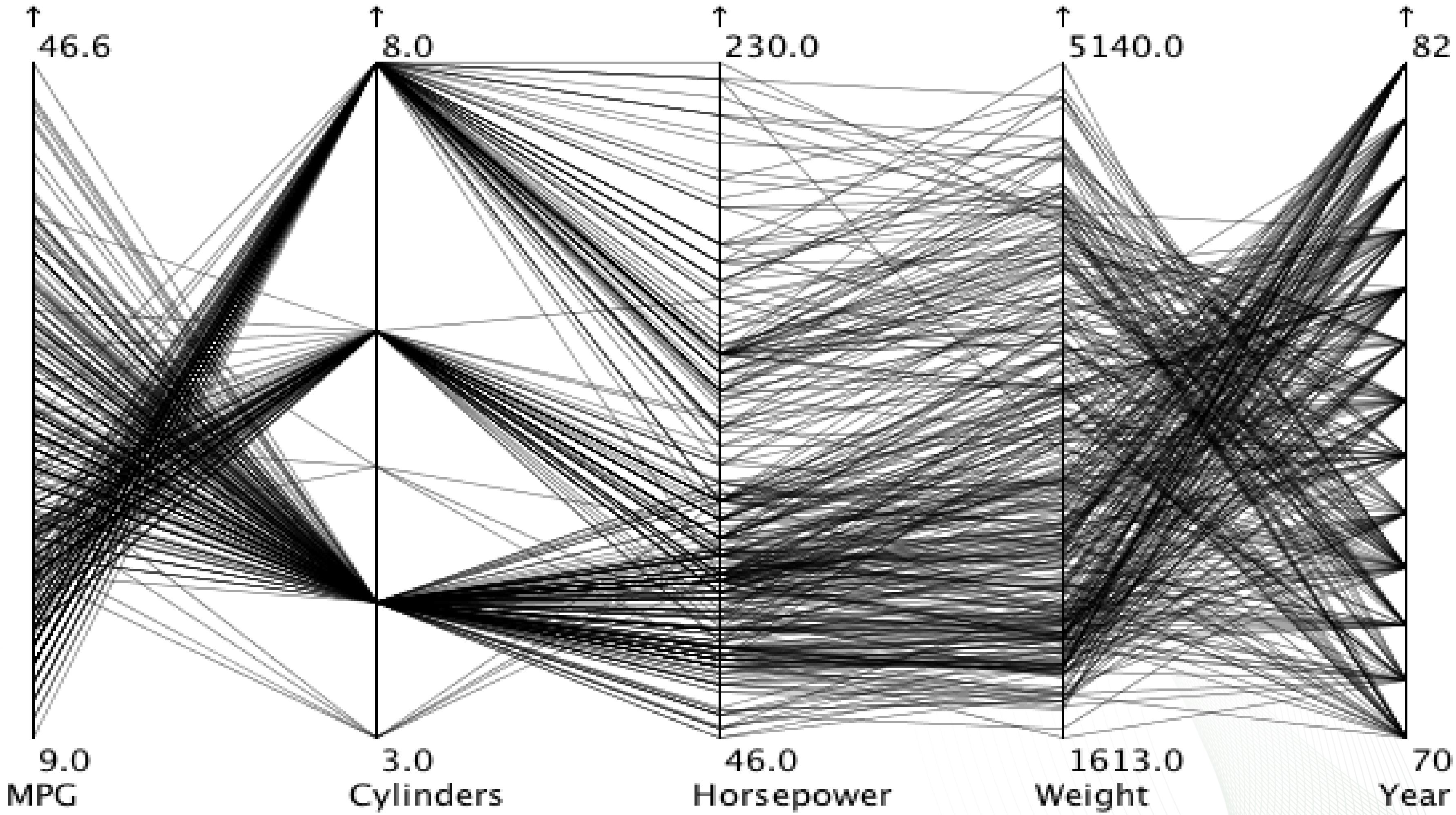
# PCP - car data set



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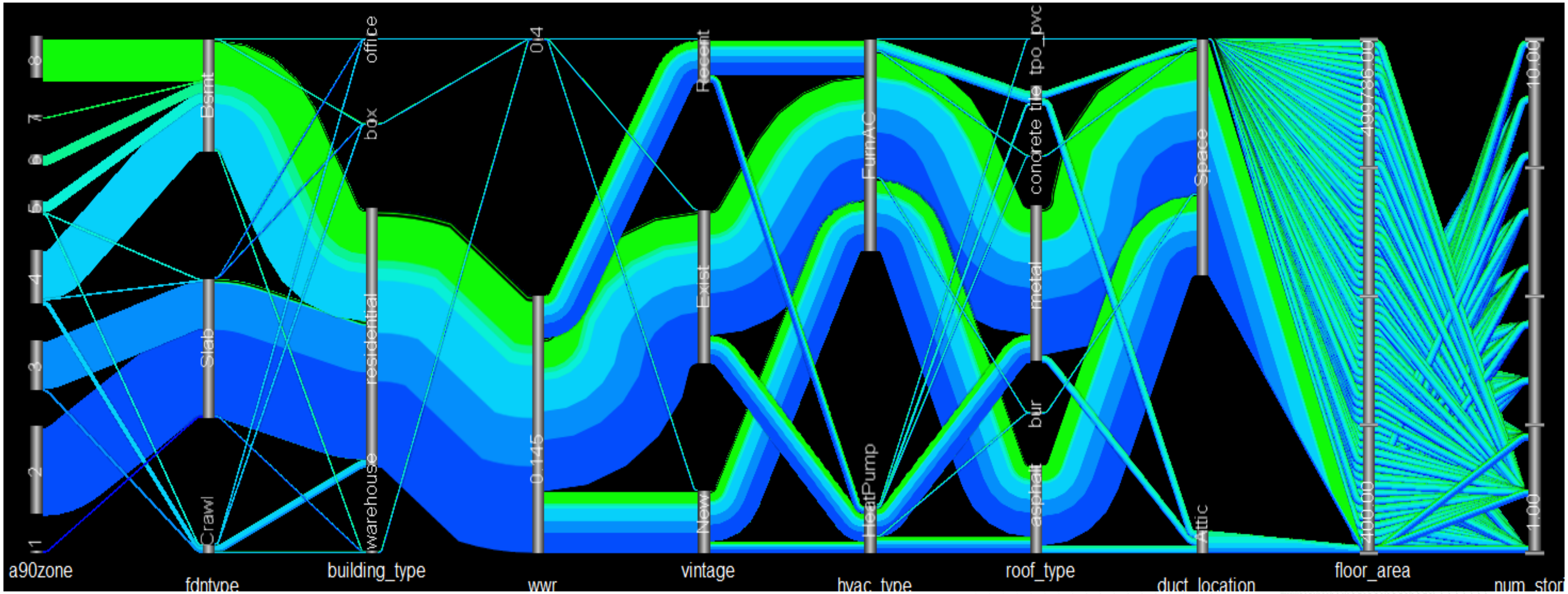
# PCP bin rendering

- Transfer function coloring:
  - Occupancy or leading axis



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# The power of "and" – linked views

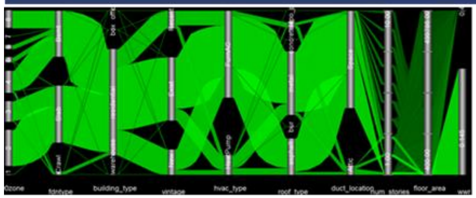
## Roof Savings Calculator

www.roofcalc.com


Dr. Joshua New (ORNL) and Chad Jones (UC-Davis)

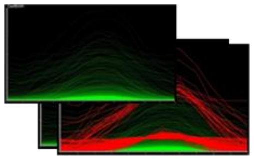
Dr. William A. Miller (ORNL), A. Desjarlais (ORNL), Yu Joe Huang (WhiteBox), Ender Erdem (WhiteBox)


### Multivariate Visualization of Large-Scale Parameter Sweeps



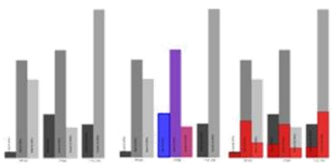
Parallel Coordinates Plots

+



Time-variant Function Plots

+

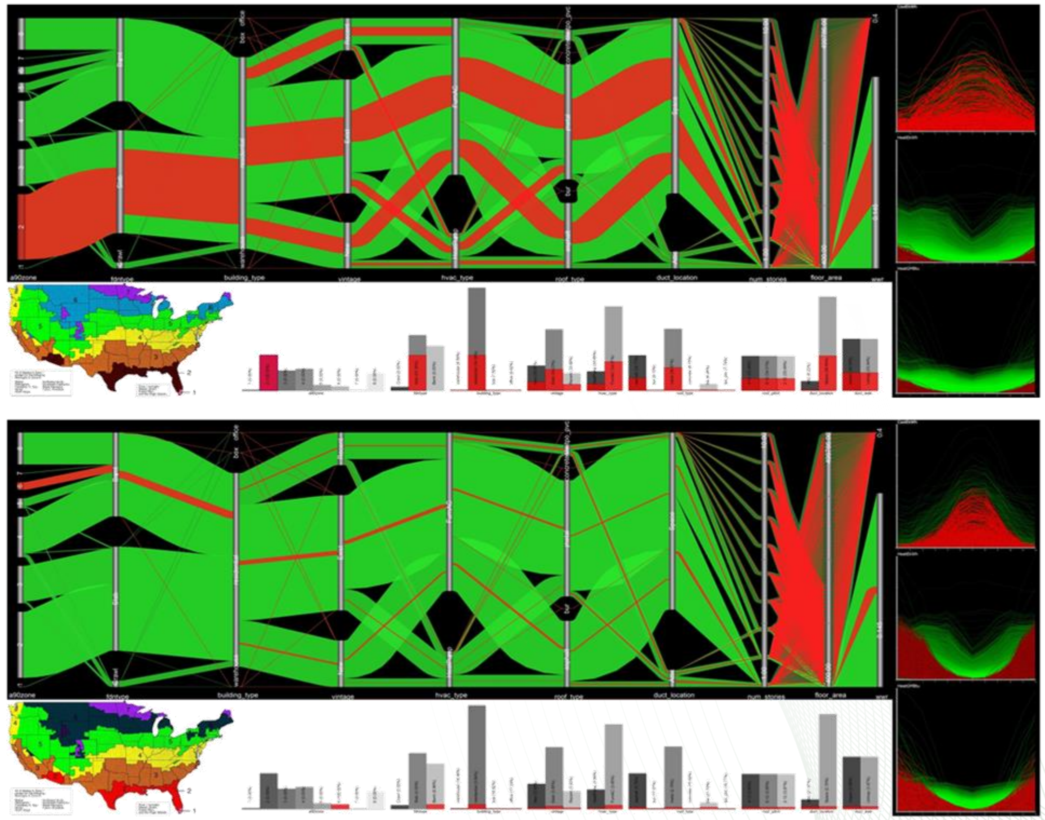


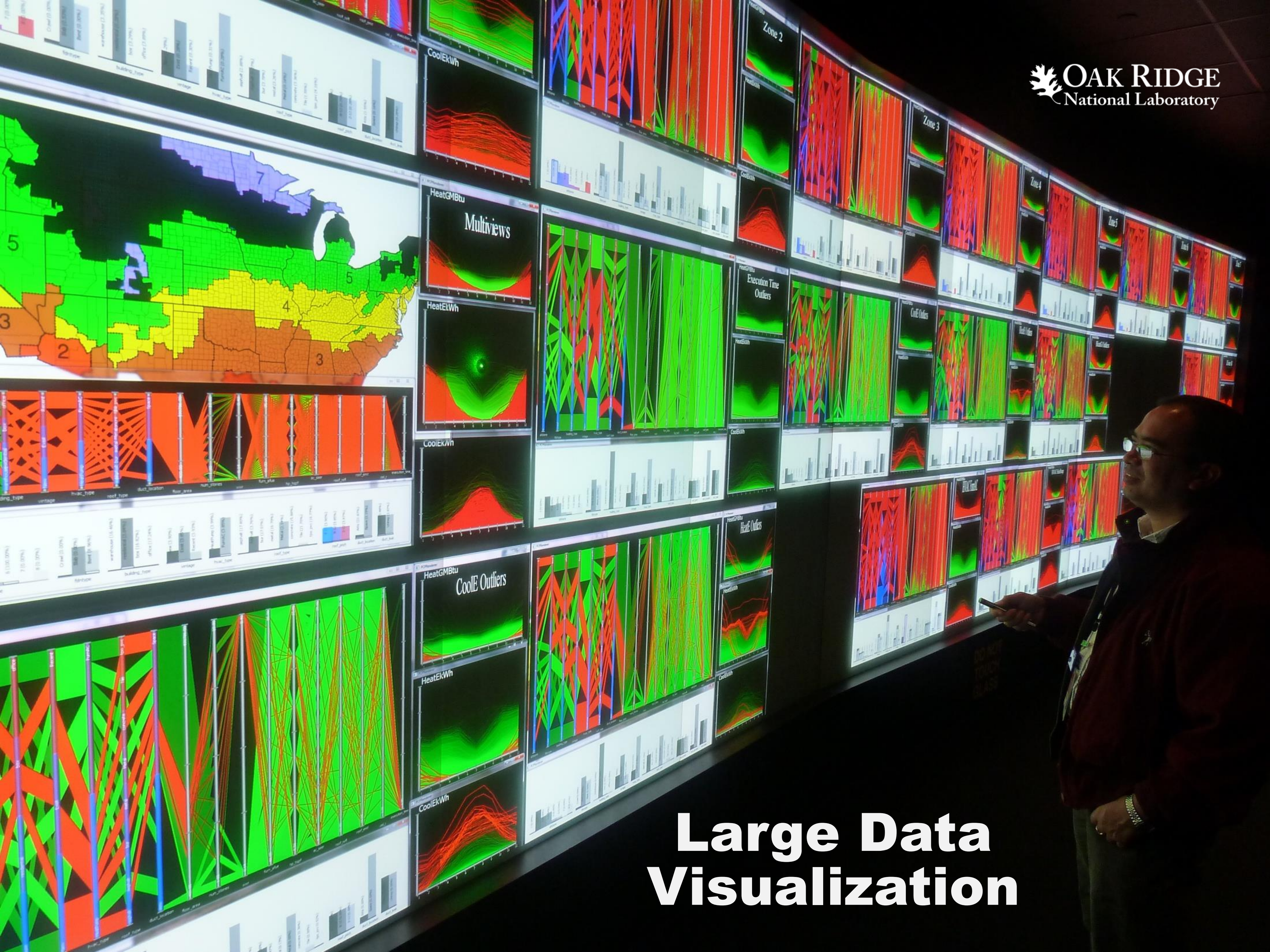
Category Charts

+

Climate Zone Map

=

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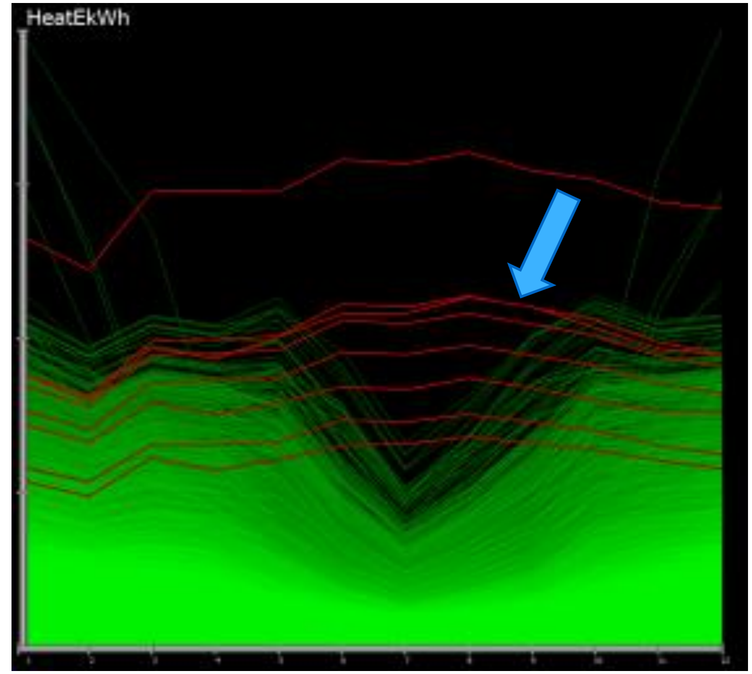
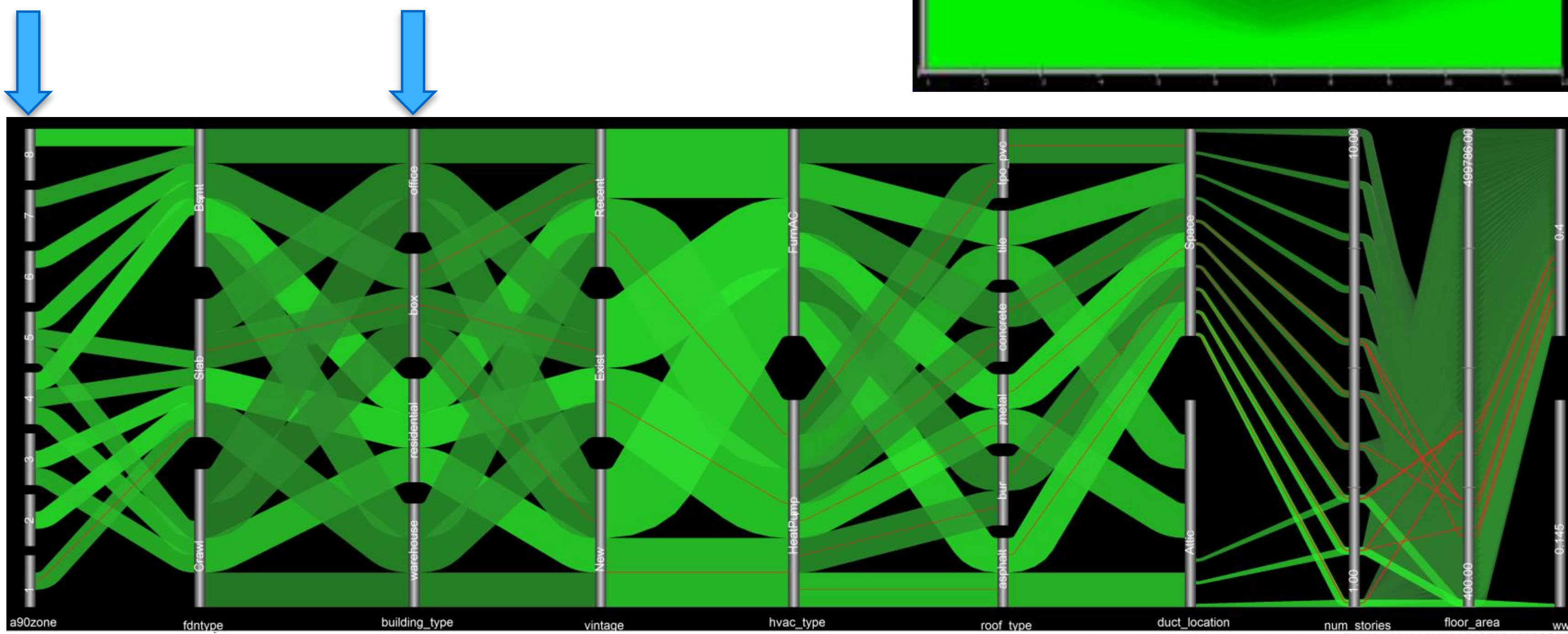
National Laboratory
Multiviews
CoolE Outliers
Execution Time Outliers
Zone 2
Zone 3
HeatGMBtu
HeatEkWh
CoolEkWh
Large Data Visualization

# Outliers (heating)




- Selection of heating outliers
- Find all have box building type and in Miami



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# Impact – RSC and Visual Analytics

**12 Publications, 20+ organizations interested (licensing)**

New, Joshua R., Huang, Yu (Joe), Levinson, Ronnen, Mellot, Joe, Sanyal, Jibonananda, Miller, William A., and Childs, Kenneth W. (2013). "Analysis of DOE's Roof Savings Calculator with Comparison to other Simulation Engines" ORNL internal report ORNL/TM-2013/501, November 1, 2013, 63 pages.

Mellot, Joseph W., Sanyal, Jibonananda, and New, Joshua R. (2013). "Preliminary Analysis of Energy Consumption for Cool Roofing Measures." Presented at the International Reflective Roofing Symposium, the American Coating Association's (ACA) conference, and in *Proceedings of the ACA's Coating Regulations and Analytical Methods Conference*, Pittsburgh, PA, May 14-15, 2013.

Jones, Chad, New, Joshua R., Sanyal, Jibonananda, and Ma, Kwan-Liu (2012). "Visual Analytics for Roof Savings Calculator Ensembles." In *Proceedings of the 2nd Energy Informatics Conference*, Atlanta, GA, Oct. 6, 2012.

Cheng, Mengdawn, Miller, William (Bill), New, Joshua R., and Berdahl, Paul (2011). "Understanding the Long-Term Effects of Environmental Exposure on Roof Reflectance in California." In *Journal of Construction and Building Materials*, volume 26, issue 1, pp. 516-26, August 2011.

New, Joshua R., Miller, William (Bill), Desjarlais, A., Huang, Yu Joe, and Erdem, E. (2011). "Development of a Roof Savings Calculator." In *Proceedings of the RCI 26th International Convention and Trade Show*, Reno, NV, April 2011.

Miller, William A., New, Joshua R., Desjarlais, Andre O., Huang, Yu (Joe), Erdem, Ender, and Levinson, Ronnen (2010). "Task 2.5.4 - Development of an Energy Savings Calculator." California Energy Commissions (CEC) PIER Project, ORNL internal report ORNL/TM-2010/111, March 2010, 32 pages.

# Presentation summary

- Scientific Paradigms
- Roof Savings Calculator
- Visual Analytics
- Knowledge Work (context)
- Autotune
- Example Data Tools
- Saving Money



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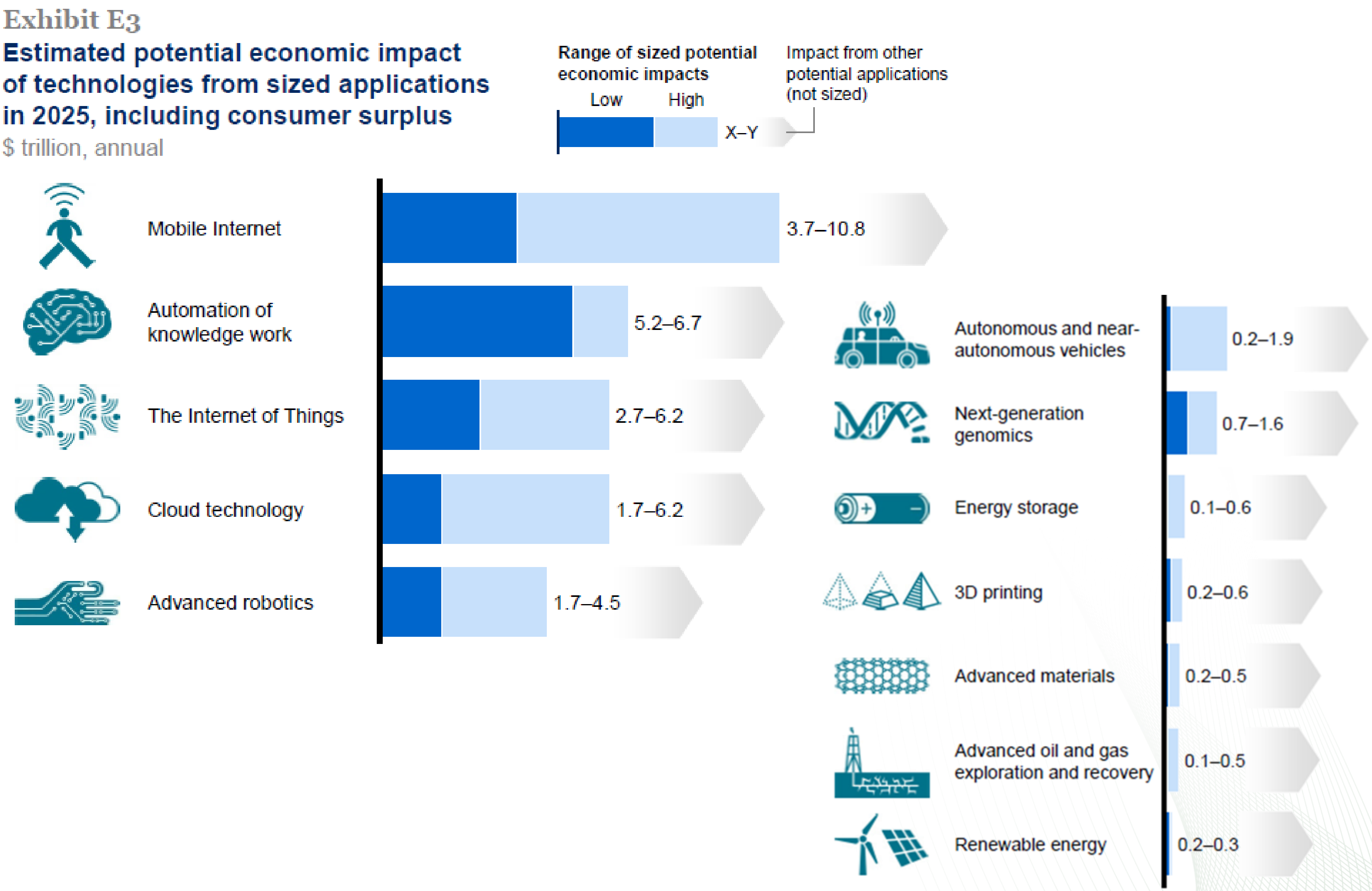
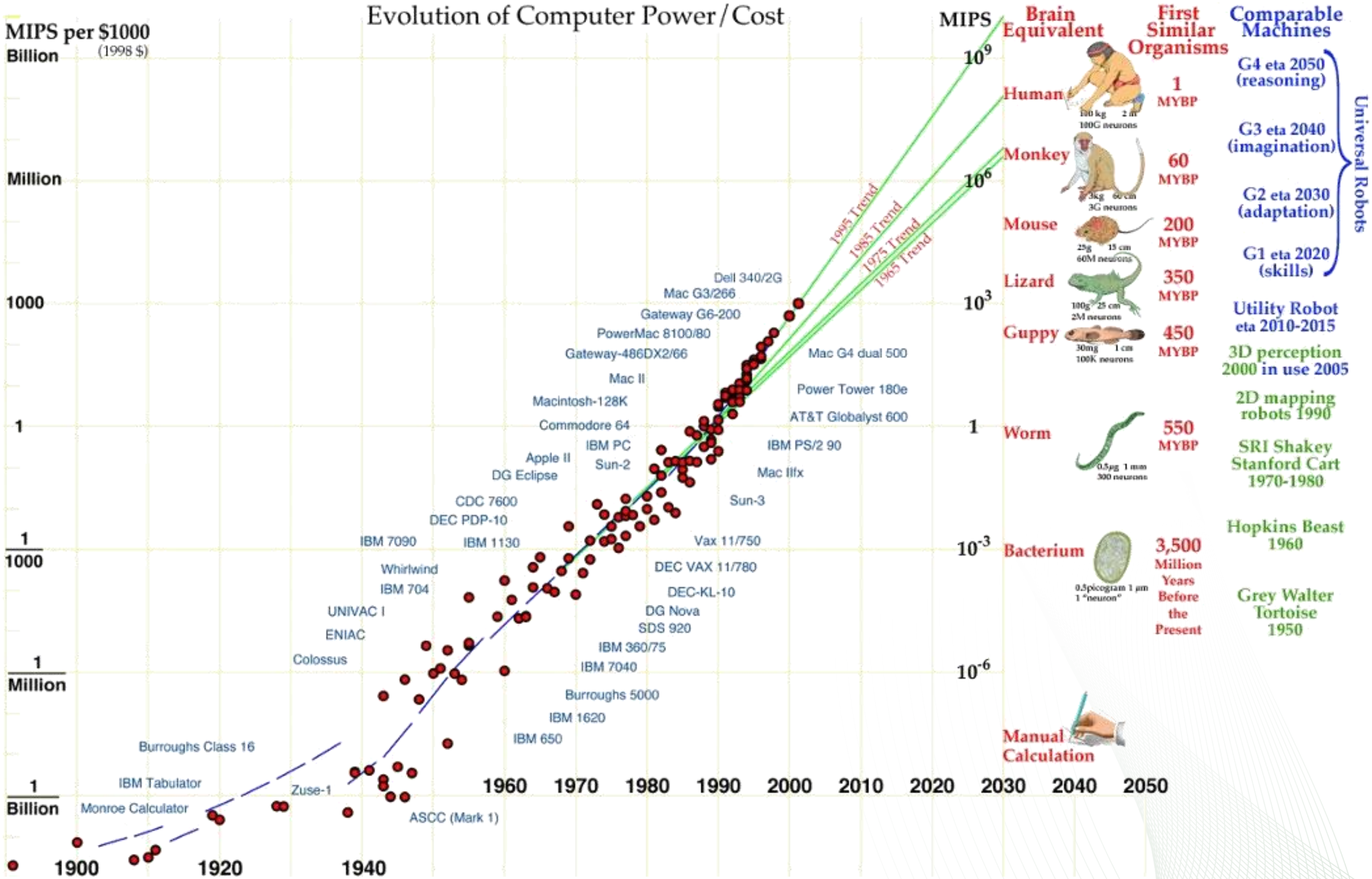
# McKinsey Global Institute Analysis




Source: McKinsey Global Institute analysis

# $1000 machine helping meat machines

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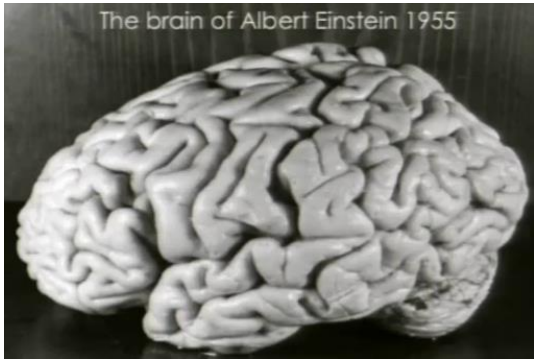
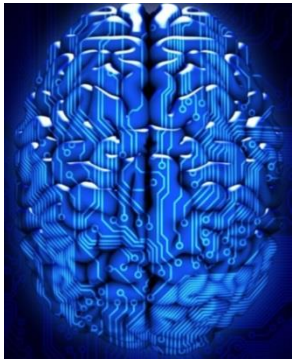
# Humans and computers

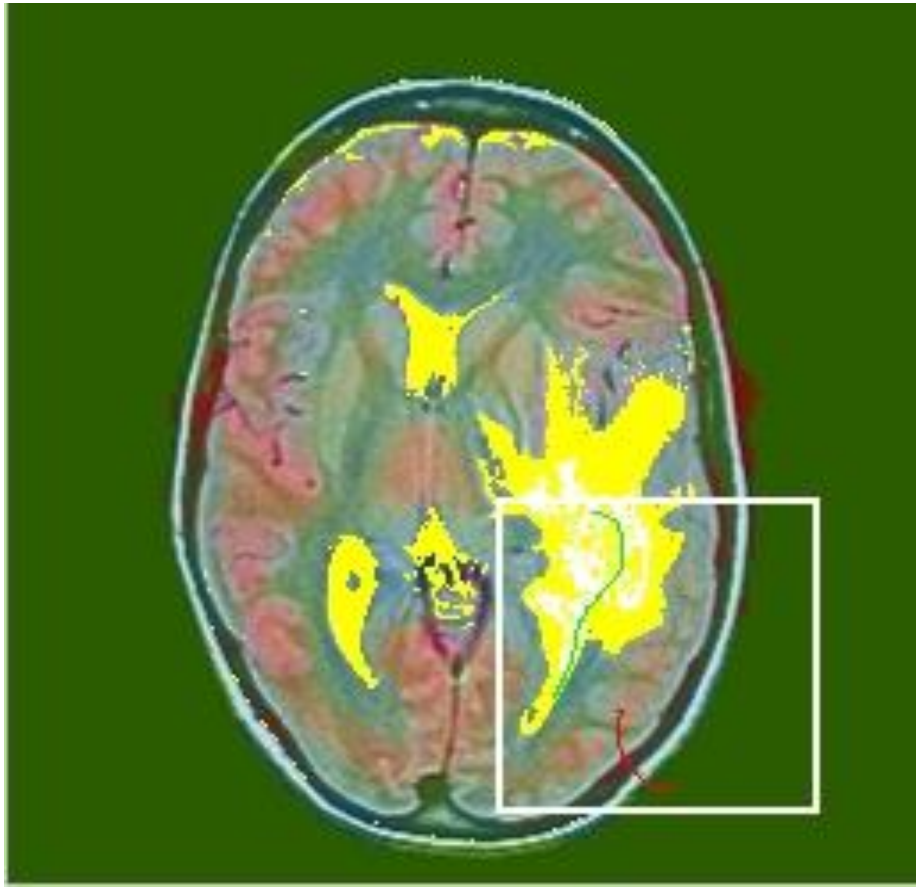


- 3 lbs (2%), 20 watts (20%)
- 120-150 billion neurons
- 100 trillion synapses
  – Firing time ~milliseconds
- 11 million bits/second input
  – Consciousness - 40 bits/second
- Working memory – 4-9 words
- Long-term memory – 1-1k TB
- Complex, self-organizing

- PC – 40 lbs, 500 watts
- 4 cores
- 3 billion Hz
  – Firing time ~nanoseconds
- 100 million bits/second
  – Not yet
- 62,500,000 words
- Disk – 3TB, perfect recall
- "Dumb", Artificial Intel.

# Learning associations



Full Results

Detailed Results



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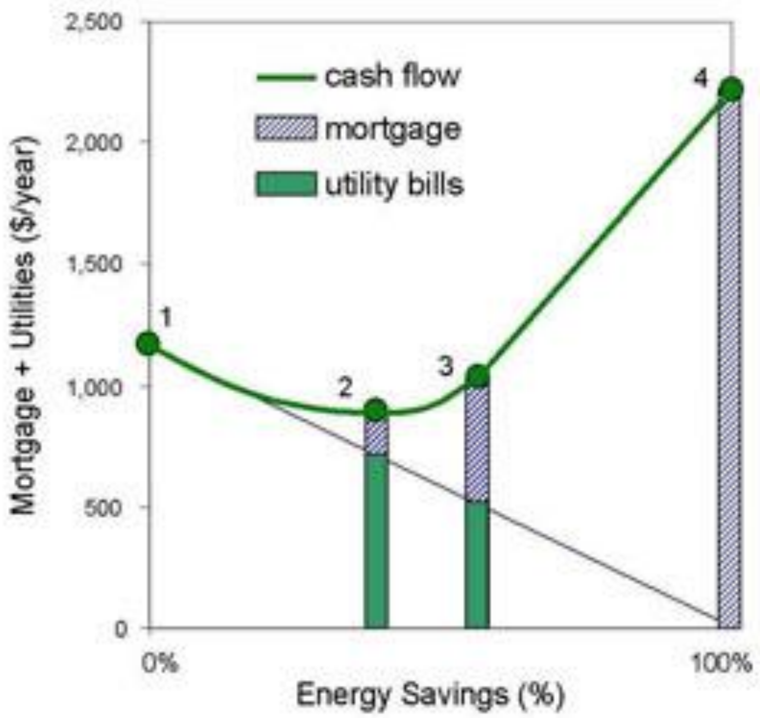
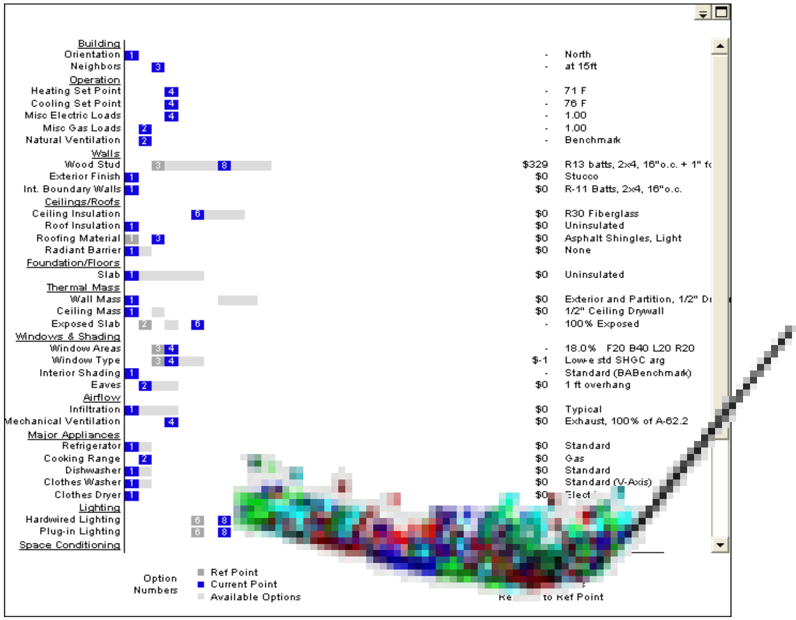
# Presentation summary

- Scientific Paradigms
- Roof Savings Calculator
- Visual Analytics
- Knowledge Work (context)
- Autotune
- Example Data Tools
- Saving Money

# Existing tools for retrofit optimization




Simulation Engine

DOE–$65M (1995–?)

EnergyPlus

API

OpenStudio

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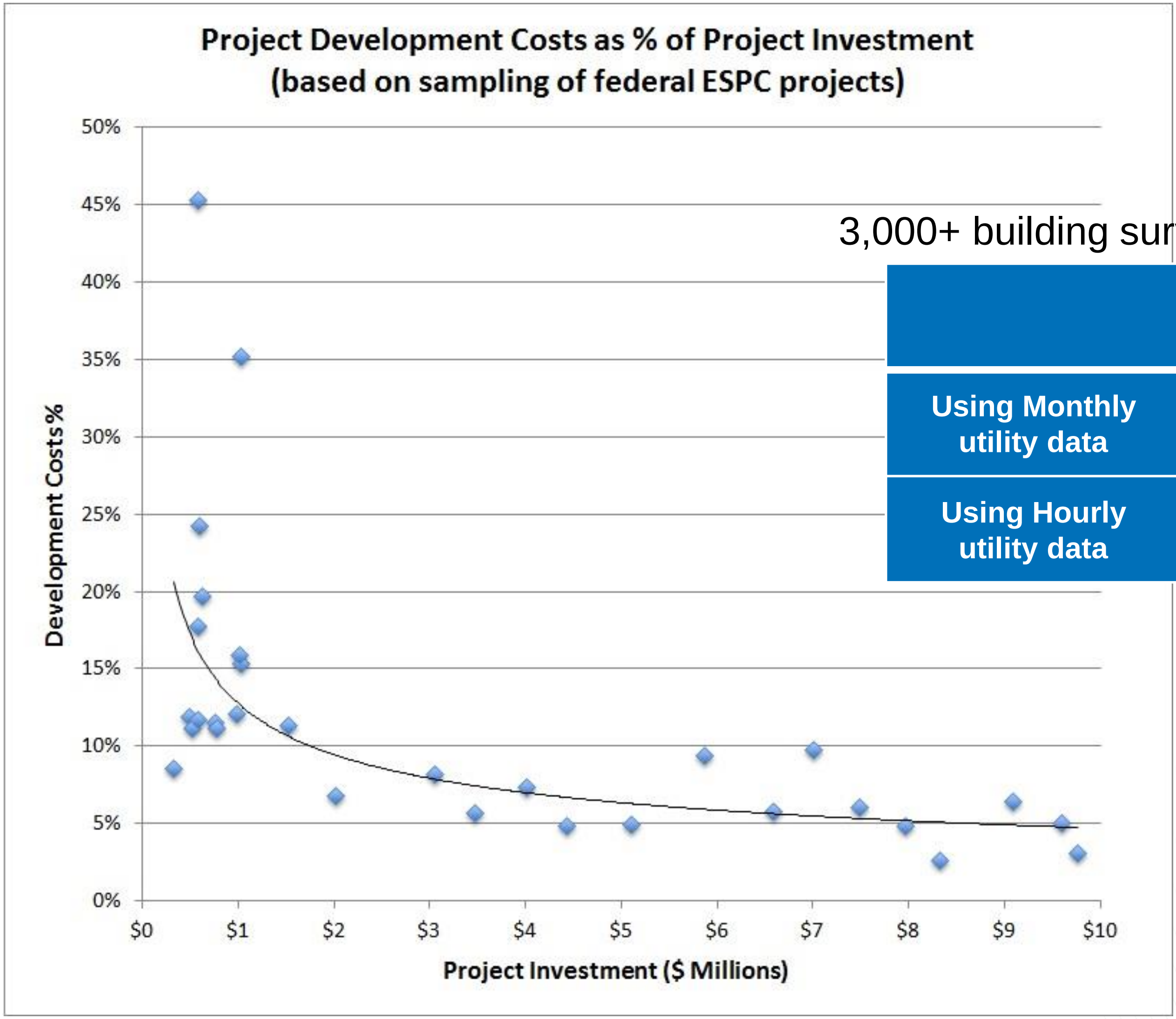
# Business limitations for M&V




3,000+ building survey, 23-97% monthly error

| | | ASHRAE G14 Requires |
|---|---|---|
| Using Monthly utility data | CV(RMSE) | 15% |
| | NMBE | 5% |
| Using Hourly utility data | CV(RMSE) | 30% |
| | NMBE | 10% |



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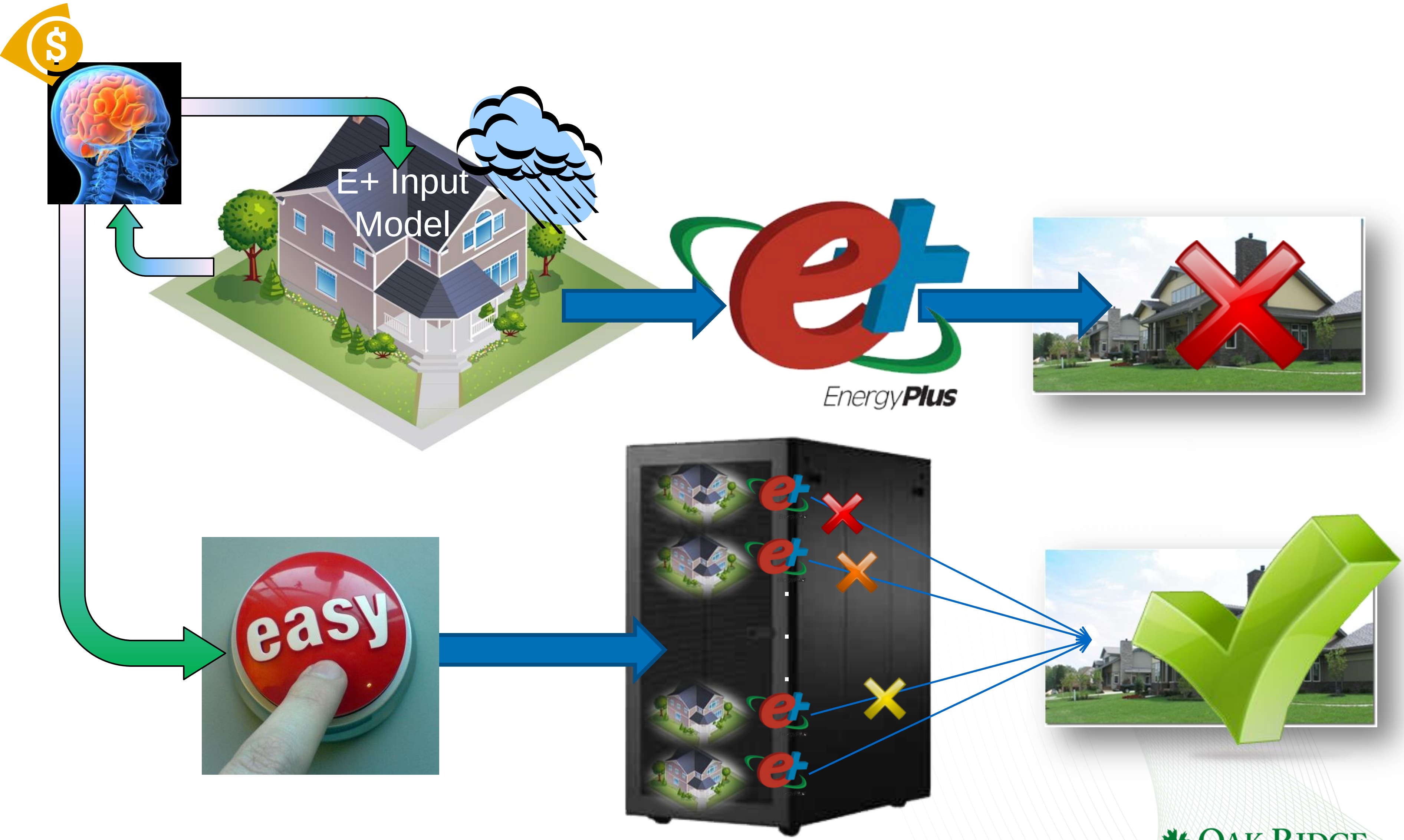
# The Autotune Idea
## Automatic calibration of software to data



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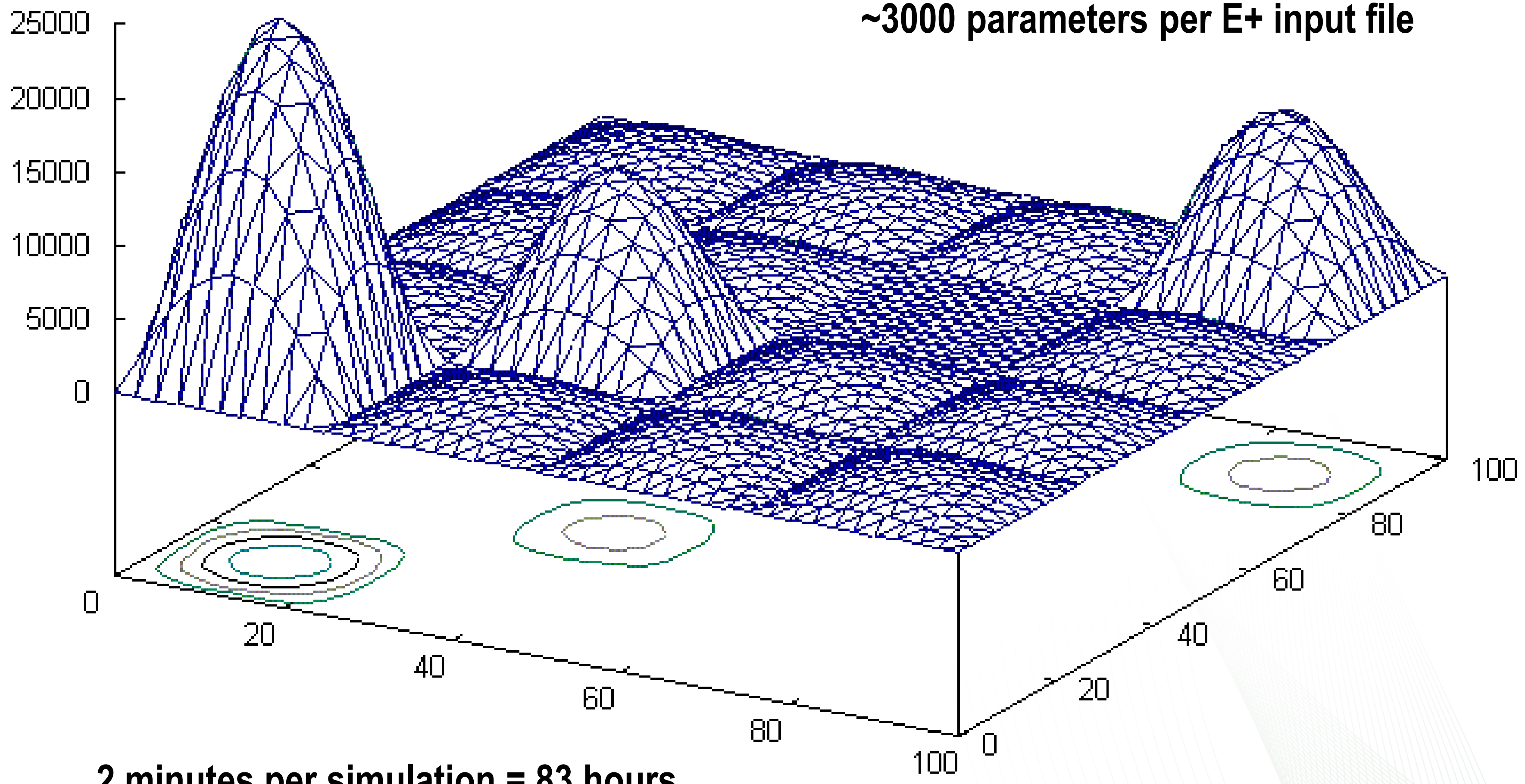
# The search problem




**Problem/Opportunity:**
**~3000 parameters per E+ input file**

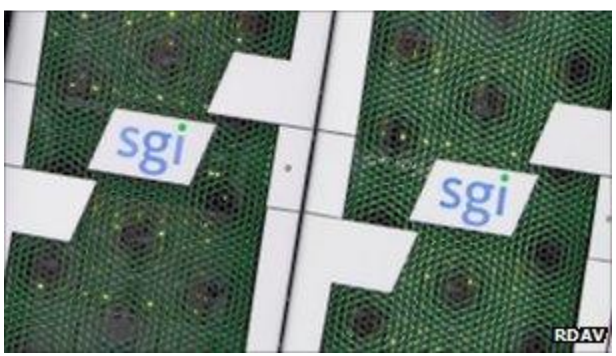
**2 minutes per simulation = 83 hours**

# ORNL High Performance Computing Resources


**Titan:**
299,008 CPU cores
18,688 GPU cores
710TB memory, distributed

**Jaguar:**
224,256 cores
360TB memory


**Nautilus:**
1024 cores
4TB shared-memory




**Kraken:**
112,896 cores


**Gordon:**
12,608 cores
SSD

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# HPC scalability for desktop software

- EnergyPlus desktop app
- Writes files during a run
- Uses RAMdisk
- Balances simulation memory vs. result storage
- Works from directory of input files & verifies result
- Bulk writes results to disk

**8 Million EnergyPlus Simulations**

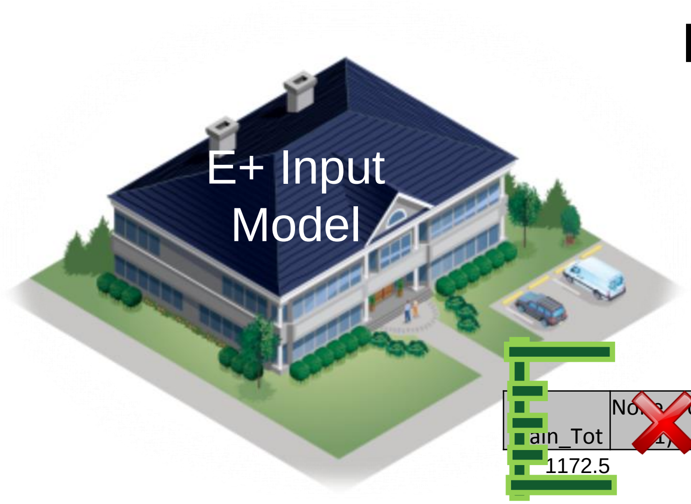
270TB dataset of energy data for buildings

| No of Processors | E+ Tasks | Wall-clock Time (mm:ss) |
|---|---|---|
| 64 | 256 | 18:34 |
| 128 | 512 | 18:22 |
| 256 | 1024 | 20:30 |
| 512 | 2048 | 20:43 |
| 1024 | 4096 | 21:03 |
| 2048 | 8192 | 21:11 |
| 4096 | 16384 | 20:00 |
| 8192 | 32768 | 26:14 |
| 16384 | 65536 | 26:11 |
| 65536 | 262144 | 44:52 |
| 131072 | 524288 | 45TB 68:08 |

*Scalability on Titan*

***Acknowledgment: Jibo Sanyal, ORNL R&D Staff***

# Computational complexity



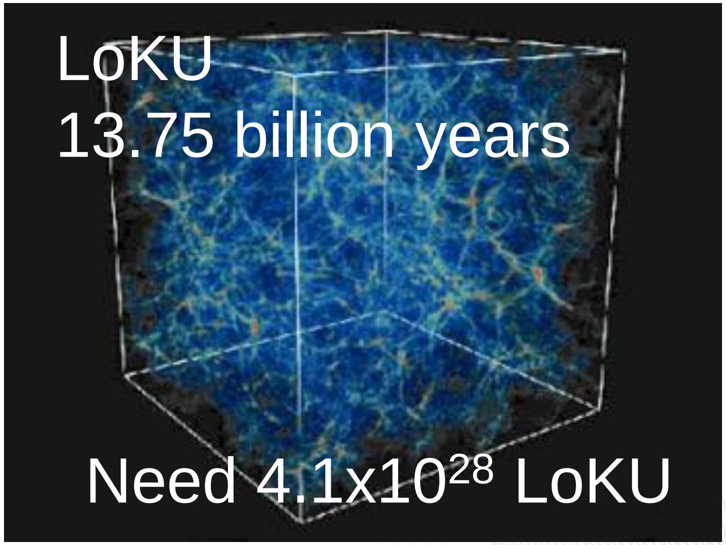

**Problems/Opportunities:**

**Domain experts chose to vary 156**

**Brute-force = $5x10^{52}$ simulations**

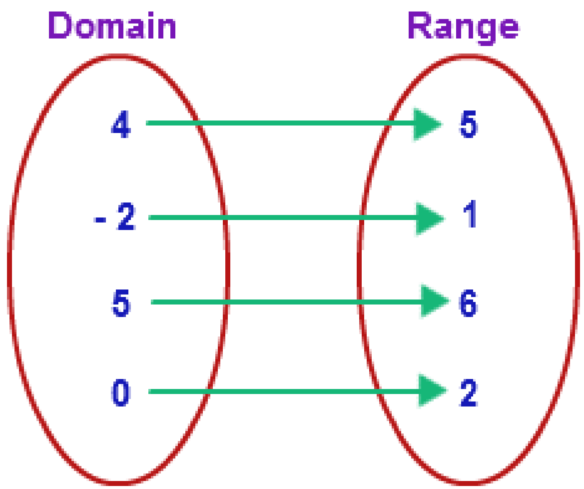
E+ parameters

| [illegible]ain_Tot | No[illegible]ot([illegible]1) | [illegible]one_Tot([illegible]2) | [illegible]1_in_Tot | [illegible]1_out_[illegible]ot | HP[illegible]ck | H[illegible]_fa[illegible]t | HP[illegible]mp | HP2_in_To | H[illegible]ut_ | HP[illegible]ck | HP2_in_fa |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1172.5 | 0 | 0 | 6.75 | 18.75 | 0 | 0 | 0 | 6.75 | 18 | 0 | 0 |



# What is artificial intelligence?

- Give it (lots of) data
- It maps one set of data to another
- Paradigms
  - Unsupervised (clustering)
  - Reinforcement (don’t run into wall)
  - Supervised (this is the real answer)
- Methods for doing that… biologically motivated or not




| | |
|---|---|
| act human | act rational |
| think human | think rational |

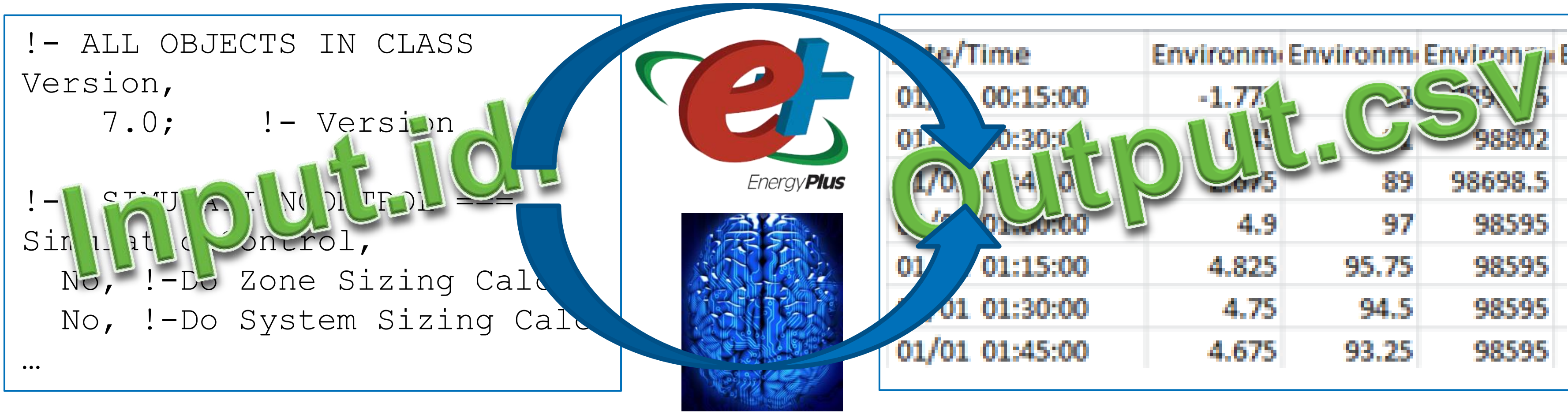
# MLSuite: HPC-enabled suite of machine learning algorithms

- Linear Regression
- Feedforward Neural Network
- Support Vector Machine Regression
- Non-Linear Regression
- K-Means with Local Models
- Gaussian Mixture Model with Local Models
- Self-Organizing Map with Local Models
- Regression Tree (using Information Gain)
- Time Modeling with Local Models
- Recurrent Neural Networks
- Genetic Algorithms
- Ensemble Learning

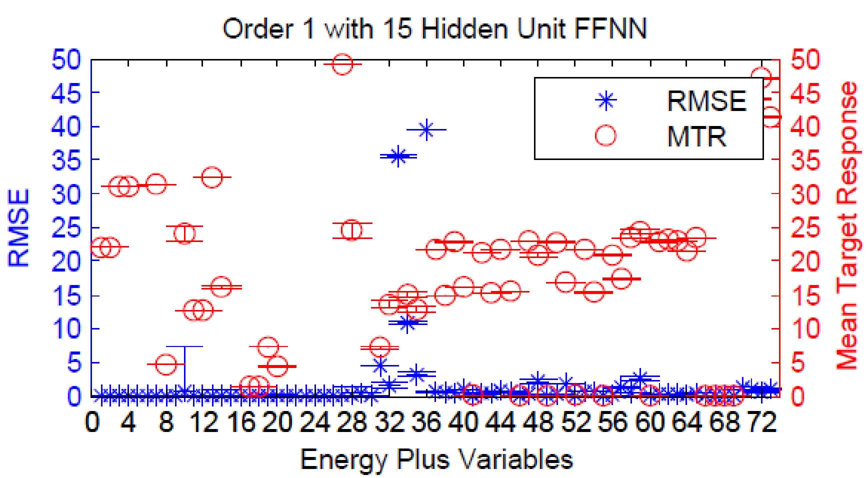
***Acknowledgment:* UTK computer science graduate graduate Richard Edwards, Ph.D. (advisor Dr. Lynne Parker); now Amazon**

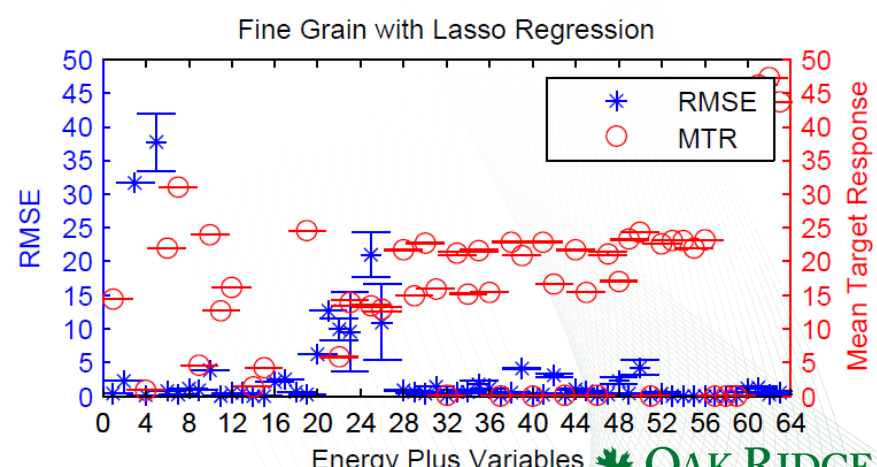
# Applications of machine learning

- EnergyPlus – 2-10 mins for an annual simulation




- ~E+ - 4 seconds AI agent as surrogate model,
  90x speedup, small error, brittle

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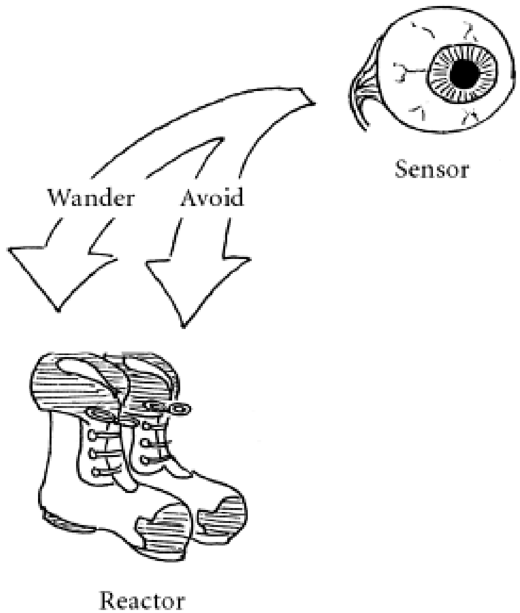
# Quote

**"the world is the best model of itself."**

**–Rodney Brooks, 1990, Elephants and nouvelle AI**




*Nouvelle AI. A robot should sense and then move according to simple rules such as "Avoid collisions" or "Wander."*



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# Source of Input Data

- 3 Campbell Creek homes (TVA, ORNL, EPRI)

- ~144 sensors/home, 15-minute data:
  - Temperature (inside/outside)
  - Plugs
  - Lights
  - Range
  - Washer
  - Radiated heat
  - Dryer
  - Refrigerator
  - Dishwasher
  - Heat pump air flow
  - Shower water flow
  - Etc.

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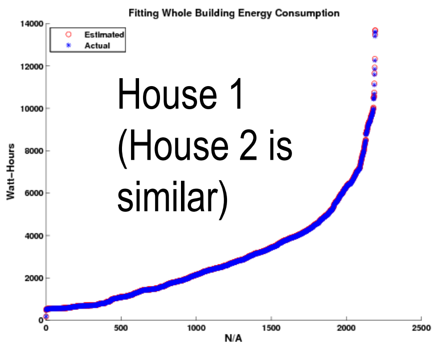
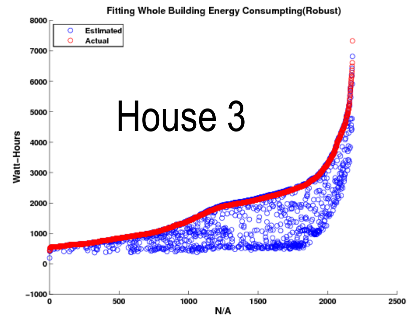
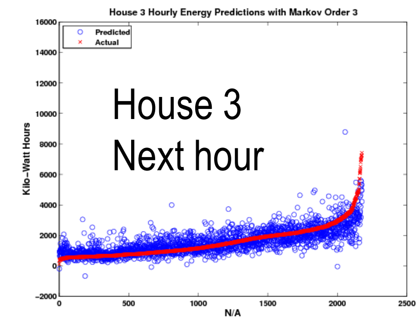
# Applications of machine learning

- Linear Regression predicting whole building energy use




- Accuracy Metrics for best subset of sensors

▸ Root Mean Squared Error(RMSE):

$$RMSE = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(y_i - p_i)^2}$$

▸ Mean Absolute Percentage of Error(MAPE):

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\frac{|y_i - p_i|}{y_i}$$

▸ Coefficient of Variance(CV):

$$CV = \frac{RMSE}{y_{mean}} \times 100$$

▸ Mean Bias Error(MBE):

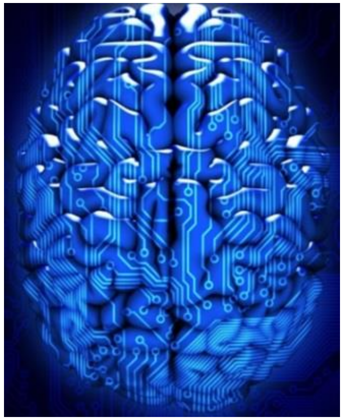
$$MBE = \frac{\frac{1}{N-1}\sum_{i=1}^{N}(y_i - p_i)}{y_{mean}} \times 100$$

| | HME FFNN | HME LS-SVM | SVR | FCM |
|---|---|---|---|---|
| RMSE(Watt-Hours) | 569.96±50.13 | 582.61±33.97 | 603.85±40.55 | 581.87±41.67 |
| MAPE(%) | 17.07±1.19 | 15.94±0.92 | 15.48±0.87 | 17.37±1.02 |
| CV(%) | 20.14±1.65 | 20.59±1.12 | 21.32±1.32 | 20.56±1.37 |
| MBE(%) | 0.42±1.17 | -0.07±0.89 | -1.50±0.80 | 0.01±0.99 |

| | Best Four Sensors | Best Model | Top 10 Sensors |
|---|---|---|---|
| RMSE | 1127.88±33.00 | 942.25±26.14 | 1129.04±32.38 |
| MAPE | 41.17±1.12 | 30.53±1.03 | 40.4483±1.29 |
| CV | 39.76±1.02 | 33.21±0.73 | 39.80±0.96 |
| MBE | -0.04±0.90 | -0.06±0.92 | -0.05±1.05 |
| ICOMP(IFIM) | 2166.3±1.54 | 1845.88±21.25 | 2125.50±2.72 |

# MLSuite: HPC-enabled Suite of Machine Learning algorithms

- Linear regression
- Feedforward neural network
- Support vector machine regression
- Non-linear regression
- K-means with local models
- Gaussian mixture model with local models
- Self-organizing map with local models
- Regression tree (using information gain)
- Time modeling with local models
- Recurrent neural networks
- Genetic algorithms
- Ensemble learning





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# Evolutionary computation

How are offspring produced?

| | Thickness | Conductivity | Density | Specific Heat |
|---|---|---|---|---|
| Bldg1 | 0.022 | 0.031 | 29.2 | 1647.3 |
| Bldg2 | 0.027 | 0.025 | 34.3 | 1402.5 |
| $(1+2)_1$ | 0.0229 | 0.029 | 34.13 | 1494.7 |
| $(1+2)_2$ | 0.0262 | 0.024 | 26.72 | 1502.9 |

- Average each component
- Add Gaussian noise
- … "AI inside of AI"



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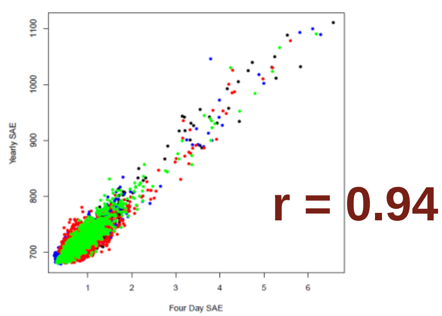
# Getting more for less

- EnergyPlus is slow
  - Full-year schedule
  - 2 minutes per simulation

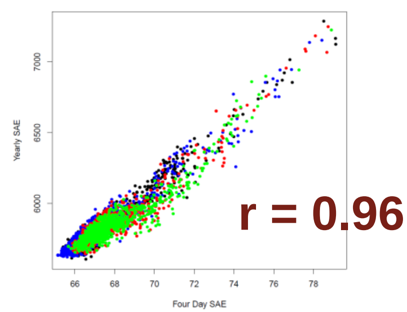
EnergyPlus

- Use abbreviated 4-day schedule instead
  - Jan 1, Apr 1, Aug 1, Nov 1
  - 10 – 20 seconds per simulation

EnergyPlus




Monthly Electrical Usage




Hourly Electrical Usage



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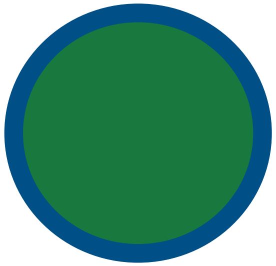
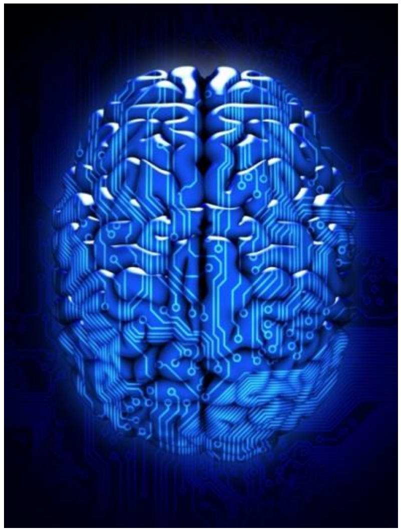
# Evolutionary combination



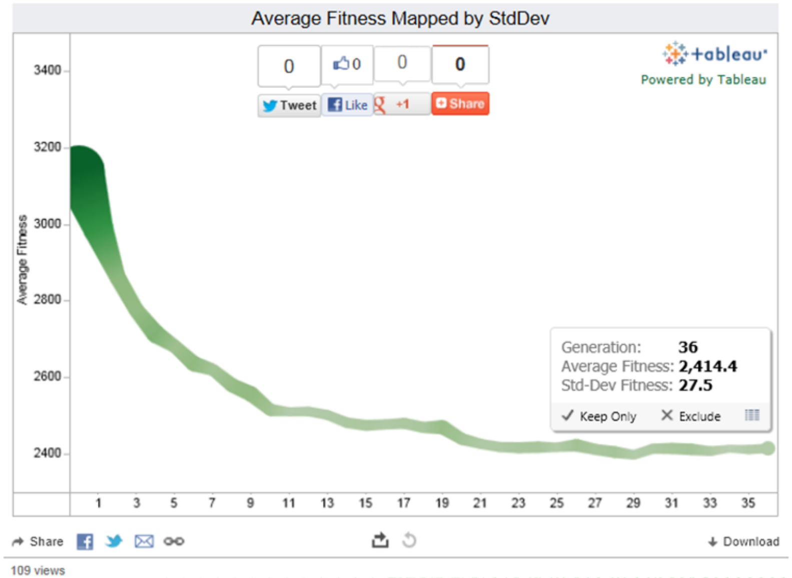


Island Hopping



**4 of 19 experiments**

1. Surrogate Modeling
2. Sensor-based Energy Modeling (sBEM)
3. Abbreviated Schedule
4. Island-model evolution



# Automated M&V process Autotune calibration of simulation to measurements

**XSEDE and DOE Office of Science** → **DOE-EERE BTO** → **Industry and building owners**

Nautilus

| No of Processors | No of E+ sims | Wall-clock Time (h:mm:ss) | Time/E+ task (mm:ss) |
|---|---|---|---|
| 32 | 32 | 0:02:08 | 2:08 |
| 64 | 64 | 0:03:04 | 3:04 |
| 128 | 128 | 0:04:11 | 4:11 |
| 128 | 1024 | 0:34:24 | 4:18 |
| 256 | 2048 | 1:25:17 | 10:40 |
| 512 | 1024 | 0:18:05 | 9:02 |

*Scalability on Nautilus*

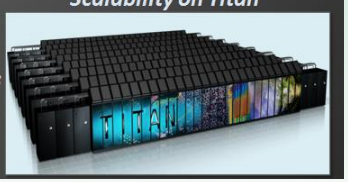
Gordon



Kraken

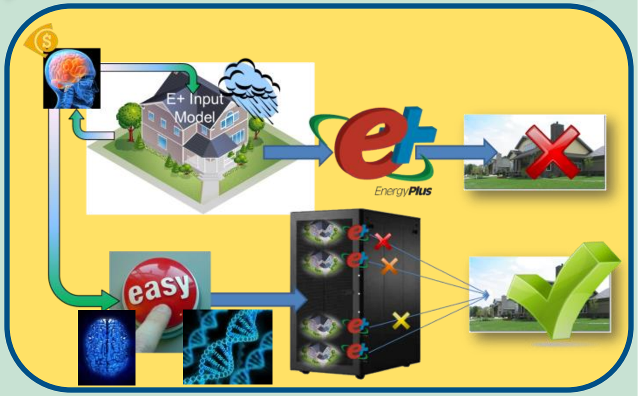
| No of Processors | E+ Tasks | | Wall-clock Time (mm:ss) |
|---|---|---|---|
| 64 | 256 | | 18:34 |
| 128 | 512 | | 18:22 |
| 256 | 1024 | | 20:30 |
| 512 | 2048 | | 20:43 |
| 1024 | 4096 | | 21:03 |
| 2048 | 8192 | | 21:11 |
| 4096 | 16384 | | 20:00 |
| 8192 | 32768 | | 26:14 |
| 16384 | 65536 | | 26:11 |
| 65536 | 262144 | | 44:52 |
| 131072 | 524288 | 45TB | 68:08 |

*Scalability on Titan*





*8 million building sims*
*270TB dataset!*
*(0.5M, 45TB, 1hr)*





**Features:**

- Works with "any" software
- Tunes 100s of variables
- Customizable distributions
- Matches 1+ million points

## Commercial Buildings

| | | ASHRAE G14 Requires | Autotune Results |
|---|---|---|---|
| Monthly utility data | CVR | 15% | 0.32% |
| | NMBE | 5% | 0.06% |
| Hourly utility data | CVR | 30% | 0.48% |
| | NMBE | 10% | 0.07% |

| Residential home | Tuned input avg. error |
|---|---|
| Within 30¢/day (actual use $4.97/day) | Hourly – 8%<br>Monthly – 15% |

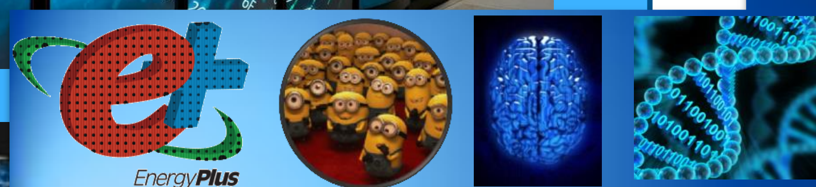
**10+ companies interested**

***Leveraging HPC resources to calibrate models for optimized building efficiency decisions***

# HPC-informed algorithmic reduction… to commodity hardware


LoKU
13.75 billion years

Need 4.1x$10^{28}$ LoKU




1 hour

# Science of how Autotune works

## Communications (33+ related publications):

1) Autotune Overview (2)

2) Large Ensemble Simulations and Big Data Challenges (2)

3) Machine Learning Techniques – on sensor data (2), MLSuite scalability on HPC (5)

4) Machine Learning applied to Calibration – Surrogate modeling (1), inverse modeling (1), PhD dissertation (1)

5) Fixing time-series (sensor) data (6), weather data (1)

6) Provenance for tracking sensor data usage (3)

7) Autotune System Results – residential ZEBRAlliance (3), comparison to manual M&V (2), commercial buildings (2), high-resolution calibration (2), and "trinity testing" (2)



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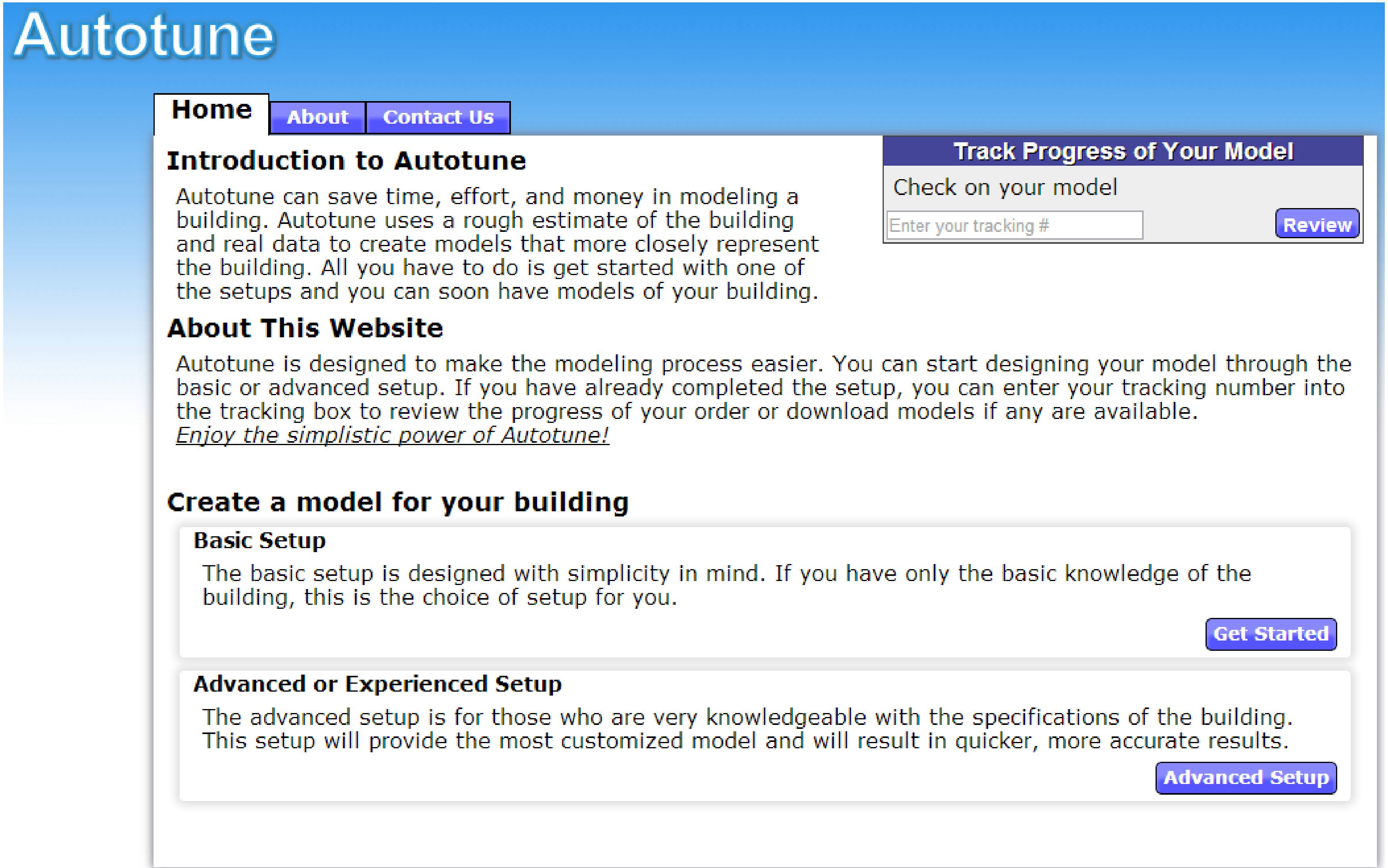
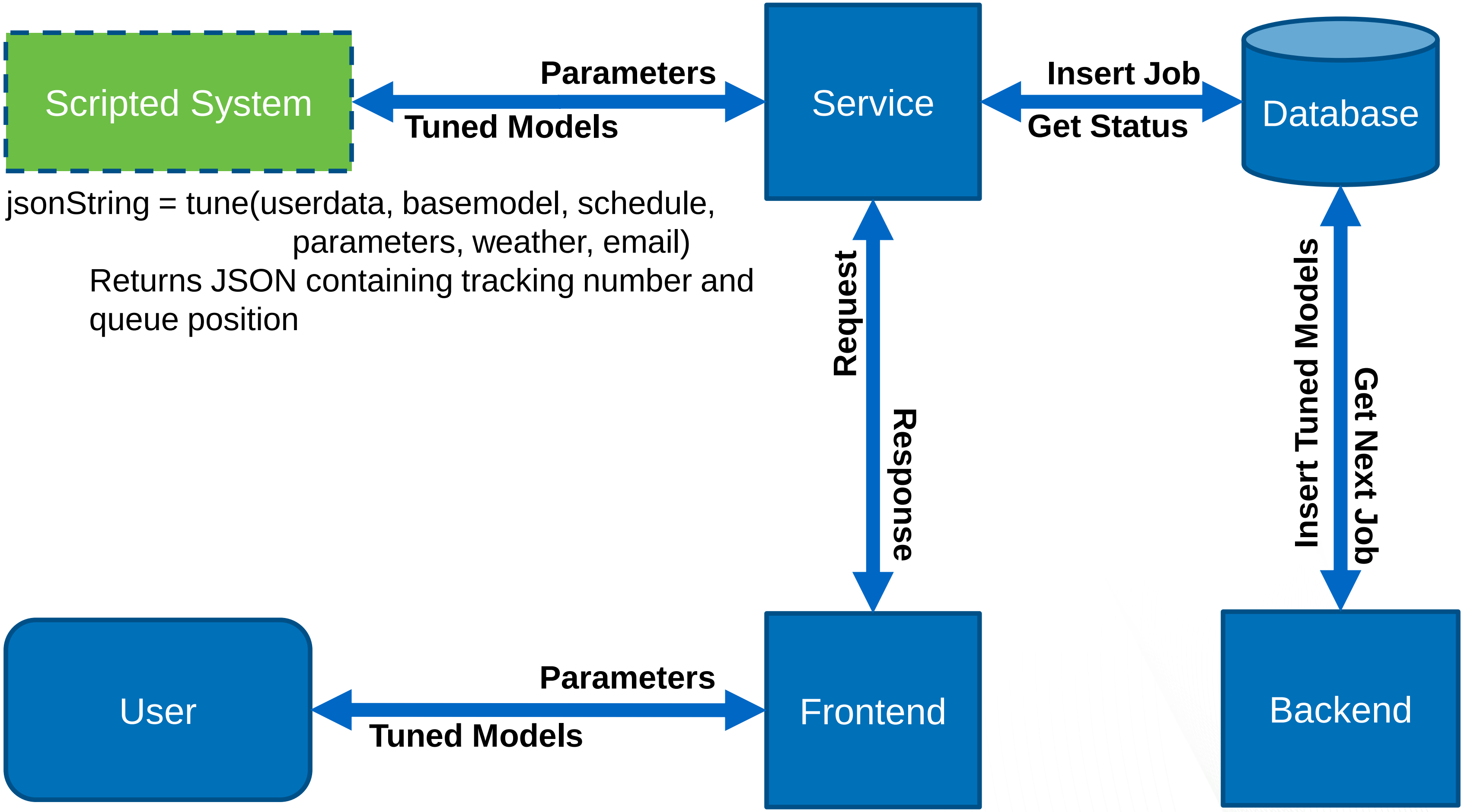
# Website


Autotune
Home
About
Contact Us
Introduction to Autotune
Autotune can save time, effort, and money in modeling a building. Autotune uses a rough estimate of the building and real data to create models that more closely represent the building. All you have to do is get started with one of the setups and you can soon have models of your building.
Track Progress of Your Model
Check on your model
Enter your tracking #
Review
About This Website
Autotune is designed to make the modeling process easier. You can start designing your model through the basic or advanced setup. If you have already completed the setup, you can enter your tracking number into the tracking box to review the progress of your order or download models if any are available.
Enjoy the simplistic power of Autotune!
Create a model for your building
Basic Setup
The basic setup is designed with simplicity in mind. If you have only the basic knowledge of the building, this is the choice of setup for you.
Get Started
Advanced or Experienced Setup
The advanced setup is for those who are very knowledgeable with the specifications of the building. This setup will provide the most customized model and will result in quicker, more accurate results.
Advanced Setup

# Website




jsonString = tune(userdata, basemodel, schedule, parameters, weather, email)

Returns JSON containing tracking number and queue position

10 companies interested, 3 have provided data

# Building 3147 Autotune results

**ENABLE IGA Tool**

Uses defaults based on building type, location, and age.

Climate Zone 4a weather file (Baltimore)

**CV(RMSE) = 119.9%**

**ENABLE IGA Tool**

Quick audit (10 min walkthrough, 3 inputs altered)

Climate Zone 4a weather file (Baltimore)

**CV(RMSE) = 33.4%**

**Local Weather (TMY3)**

Quick audit

Knoxville airport weather file (TMY3)

**CV(RMSE) = 23.3%**

**Local Weather (AMY)**

Quick audit

Oak Ridge weather file (AMY) – Warm winter

**CV(RMSE) = 9.0%**

**Autotune**

Calibrated model
Local AMY weather file

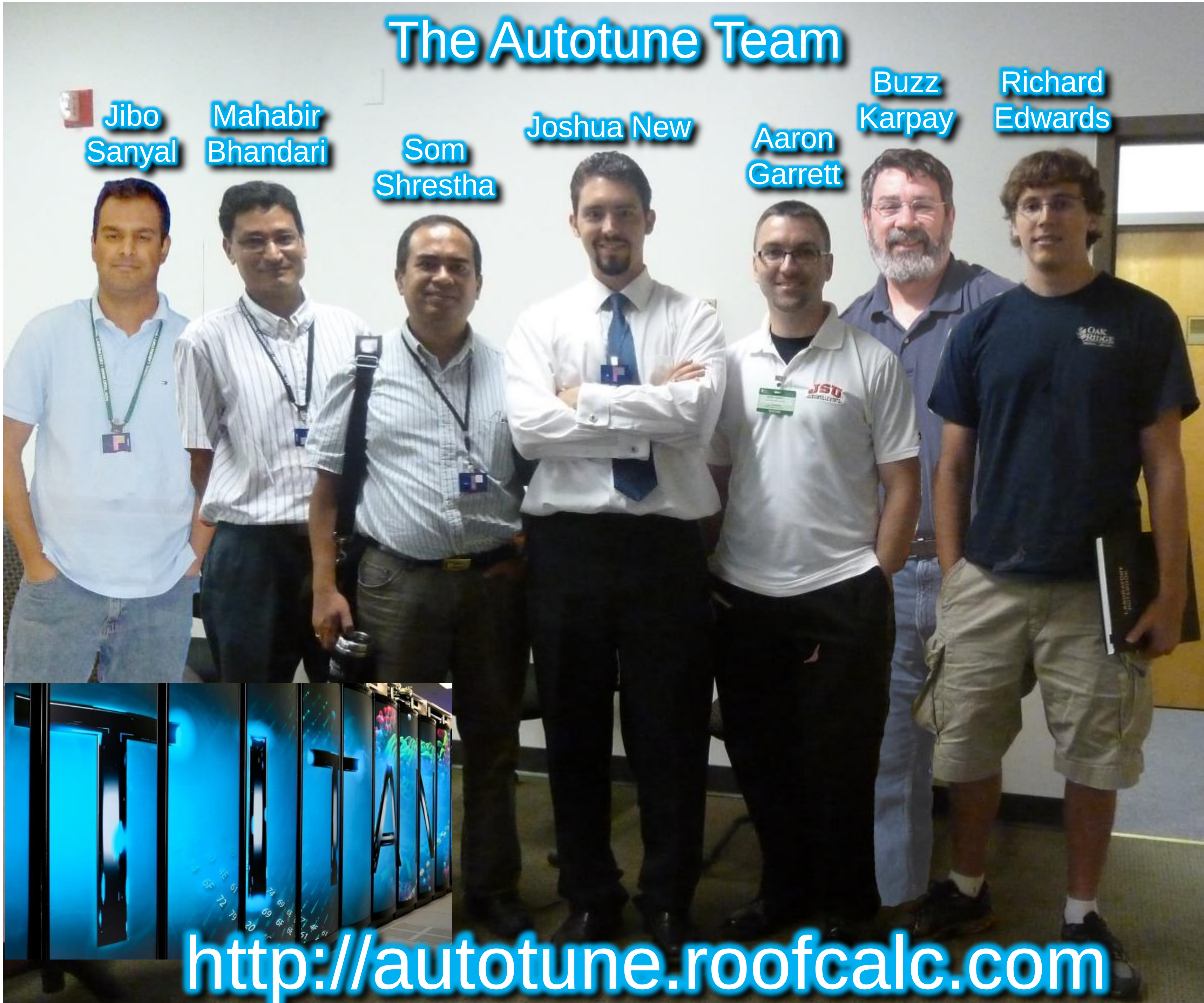
4096 simulations
12 hours on 4 cores
(48 core-hours)

Typically:
1024 simulations
~12 core-hours

ASHRAE Guide14 < 15%

**CV(RMSE) = 3.5%**

| | 15 Minute | Hourly | Daily | Monthly |
|---|---|---|---|---|
| Defaulted (climate zone TMY3) | 155.55% | 154.14% | 129.11% | 119.87% |
| Quick audit (climate zone TMY3) | 72.48% | 71.33% | 52.25% | 33.43% |
| Quick audit (local TMY3) | 63.89% | 62.60% | 41.08% | 23.33% |
| Quick audit (local AMY) | 43.30% | 41.64% | 22.18% | 9.03% |
| Tuned (local AMY) | 38.12% | 35.99% | 17.75% | 3.50% |


The Autotune Team
Jibo Sanyal
Mahabir Bhandari
Som Shrestha
Joshua New
Aaron Garrett
Buzz Karpay
Richard Edwards
TITAN
http://autotune.roofcalc.com

# “Big Ideas”

## Model US – SimCity for all US Buildings

**Data integration and computer vision for low-fidelity, wide-area software models of all existing buildings *with eventual calibration and simulation***

### Technology/Approach Summary

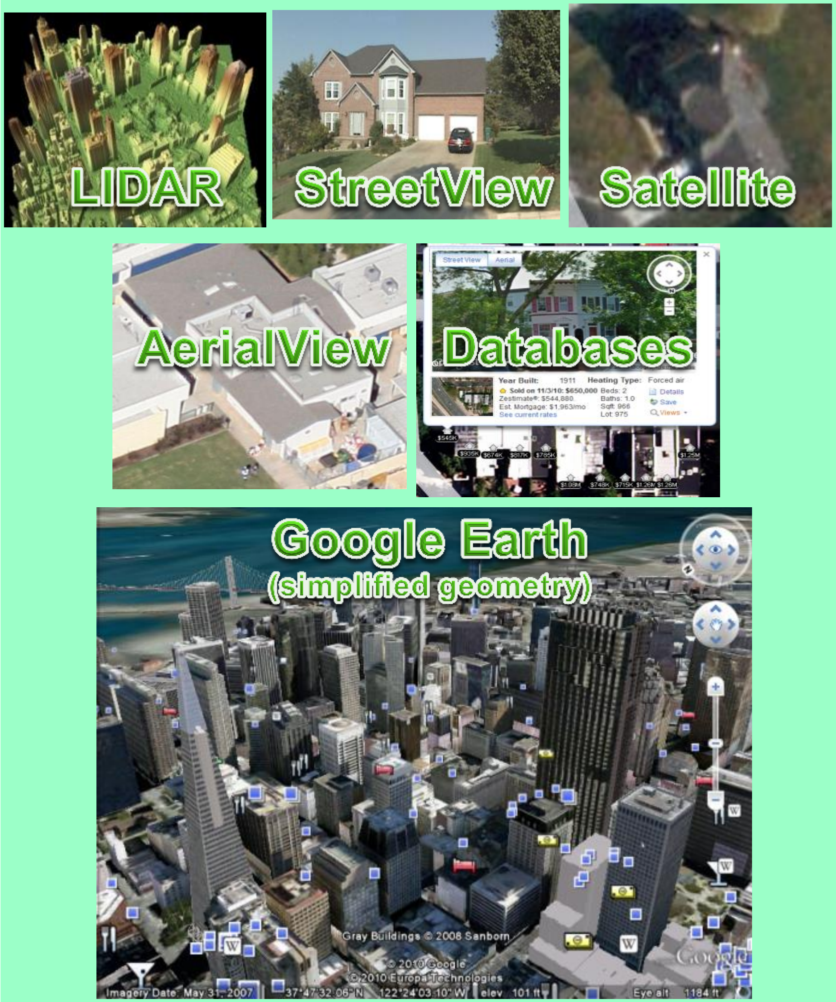
- *Consolidate building imagery for box-plot models*
- *Classify imagery via machine learning for layering box-plot models with material and equipment properties*
- *Create building database for year constructed, square footage, no. of beds and baths, heating type in public database, etc. for use by industry partners*
- *Create models with methods similar to LDRD CoNNECT used on 220,000 Knox-county buildings*
- *HPC for annual energy simulations of all US buildings (requires avg. INCITE allocation of 127M core hours)*
- *Data sources have identified databases covering 100+ million buildings, surpassing the largest DOE’s Building Technology Office database of ~30,000.*

### Technology/Approach  Impact

- *Light commercial support $5-9 billion industry*
- *ESCO revenue in 2008 was $4.1 billion, with the market served being 9% residential (public utility  programs and public housing)*
- *At 96% of the building stock, ESCO uptake could be a $12 billion dollar industry with 75% of revenue from EE*

*Data Integration, Mining, and Modeling*

Model US – 125.1 million buildings



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# Presentation summary

- Scientific Paradigms
- Roof Savings Calculator
- Visual Analytics
- Knowledge Work
- Autotune
- Example Data Tools
- Saving Money

# Campbell Creek Robo-Homes

- 3 residential homes, Campbell Creek Energy Efficient Homes Project
- Campbell Station Rd Knoxville, TN

- **Home 1:** control home, uses building techniques typical in Tennessee Valley
- **Home 2:** typical house, but retrofitted with energy efficiency technologies
- **Home 3:** uses latest construction technologies, including photovoltaic panels and solar water heating



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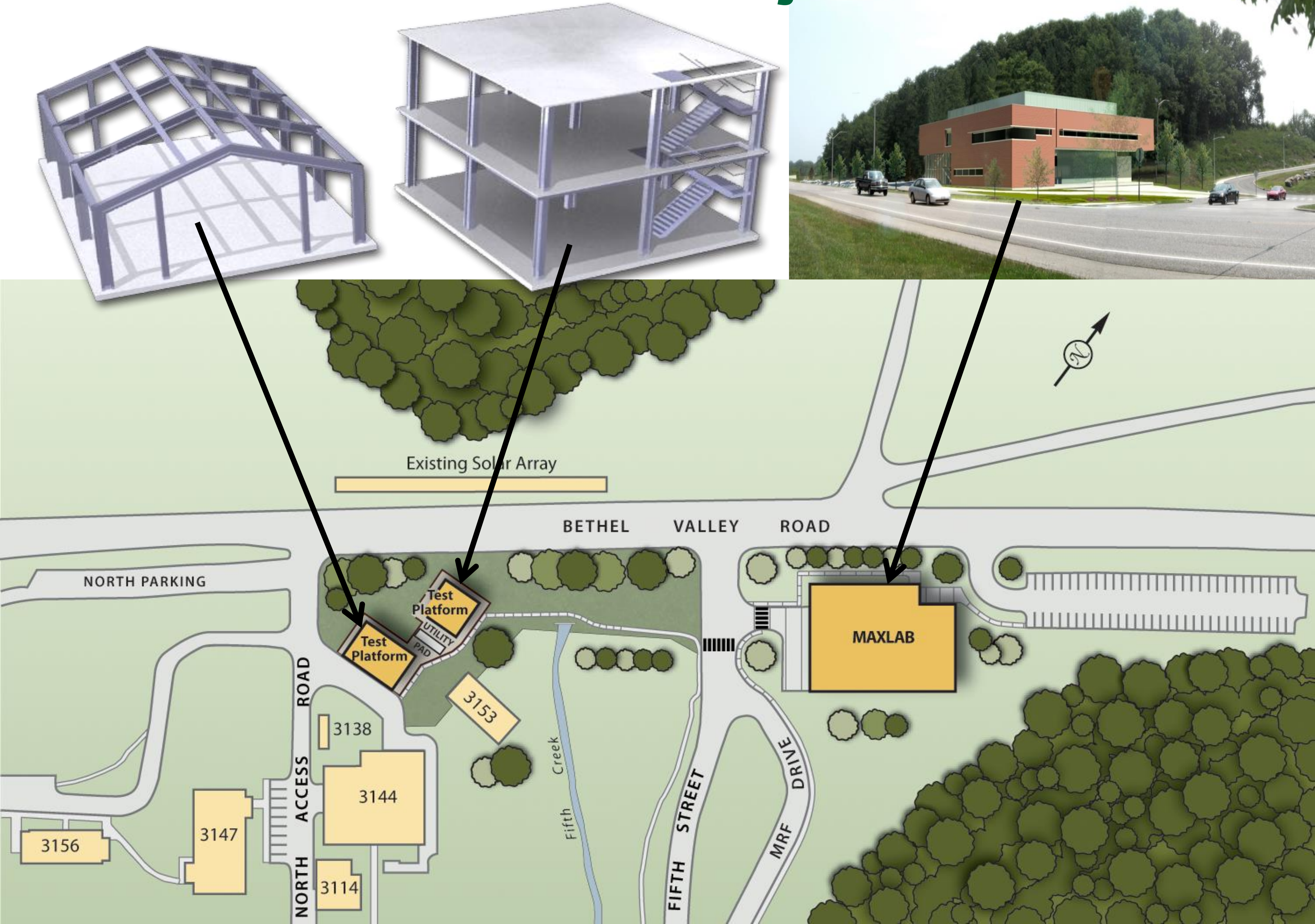
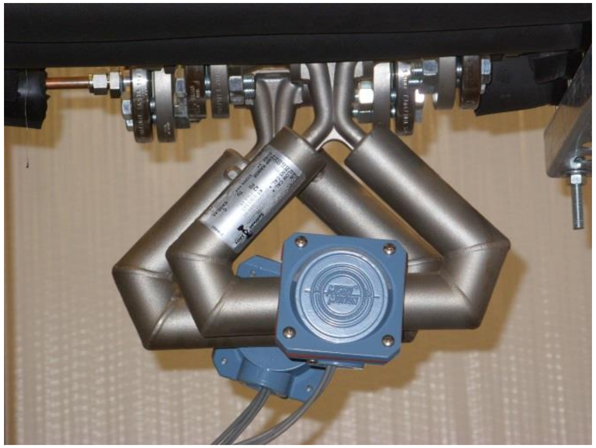
# MAXLAB Project

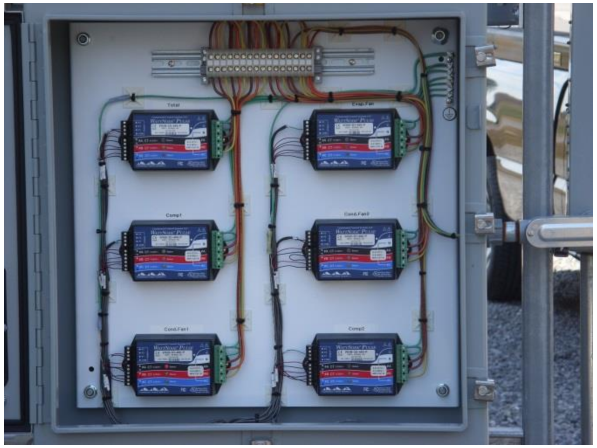


# FRP1 Sensors

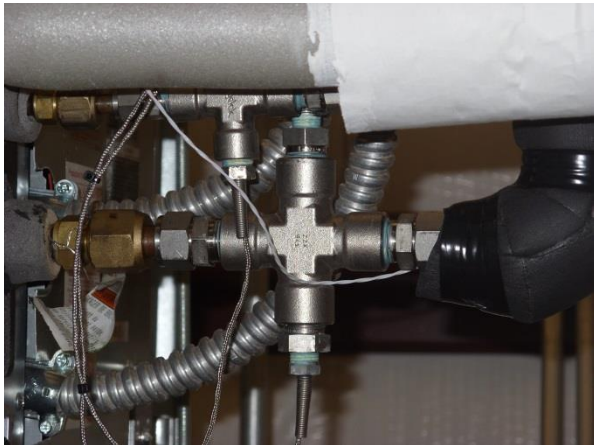


Refrigerant Mass Flow


Natural Gas Flow



Electrical Power



Refrigerant Temp and Press

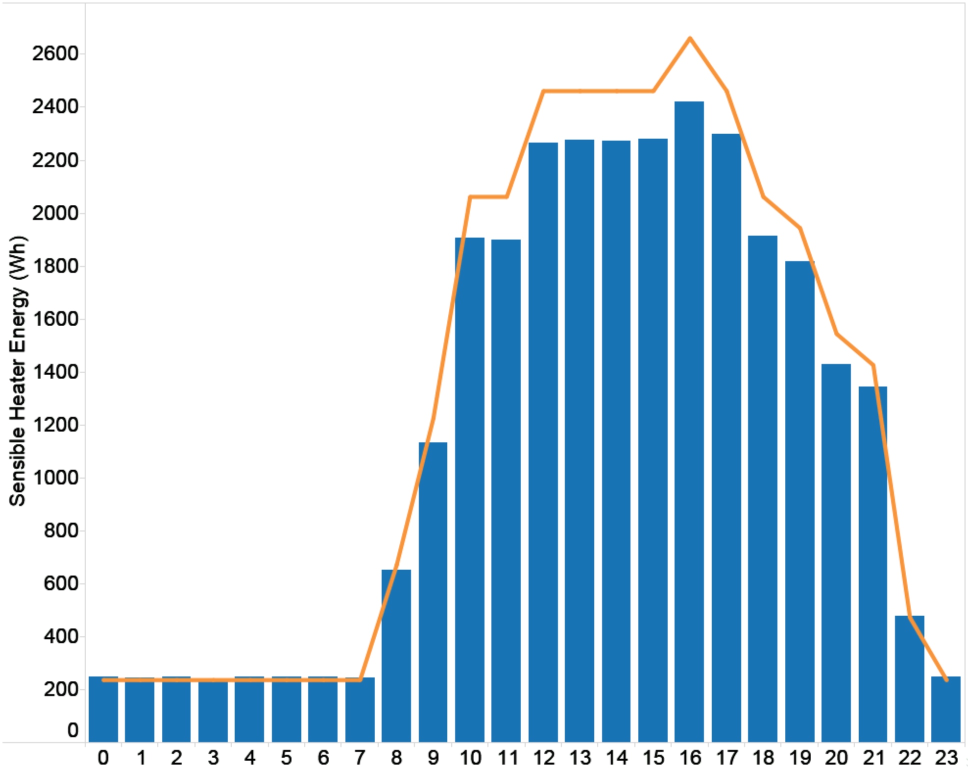
Airflow

Air Temp And RH

# Automatic filling of humidifiers

- Water lines installed for humidifier auto-fill in FRP2
- Float valves installed for auto-fill
- System includes flood protection

National Averages defined by Building America benchmarks
(dishwasher, shower, occupancy, location, heat, moisture, etc.)

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YOU NEVER KNOW WHO'S WATCHING...
(NEVER SHARE PRIVATE INFORMATION ONLINE.)


IT
Tape Backup
Elessar
EVENSTAR

# Sensor Correction

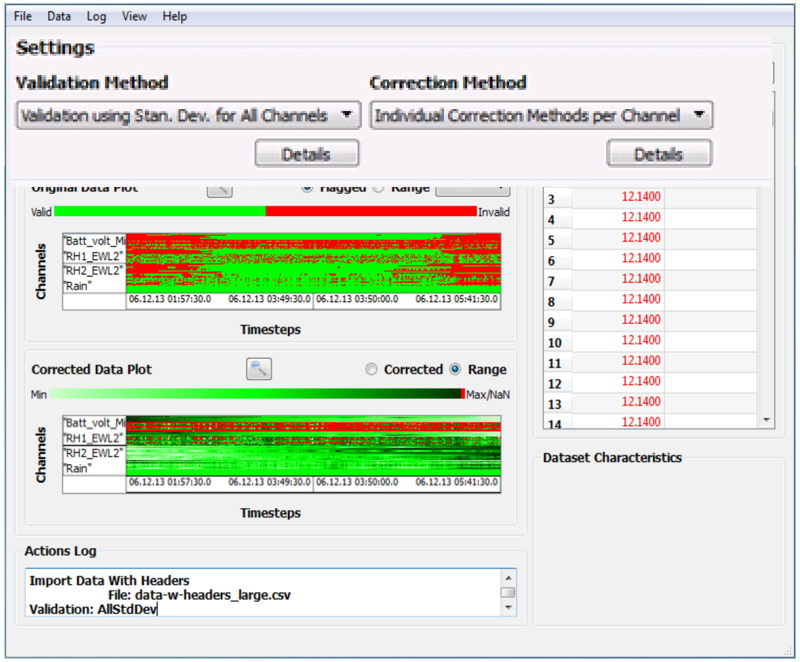


**Table 2. Summary of Testing Results for the Filtering Correction Algorithms (Castello et al. 2013)**

| | Kalman | | | | LPC | | | |
|---|---|---|---|---|---|---|---|---|
| | *w* | *AE* | *RE* | *RMSE* | *w* | *AE* | *RE* | *RMSE* |
| Temperature | 12 | 3.6% | 5.3% | 2.75 | 96 | 7.0% | 10.0% | 11.17 |
| Humidity | 96 | 5.2% | 8.9% | 5.35 | 96 | 9.2% | 15.1% | 14.36 |
| Energy | 48 | 9.7% | 468.5% | 13.75 | 4 | 9.6% | 109.1% | 12.92 |
| Pressure | 12 | 3.5% | 74.0% | 0.22 | 96 | 12.0% | 22.5% | 91.76 |
| Airflow | 4 | 0.6% | 0.3% | 0.00 | 48 | 0.6% | 66.0% | 0.98 |

**Table 1. Summary of Testing Results for the Statistical Correction Algorithms (Castello and New. 2012)**

| | Temperature | | | | Humidity | | | | Energy | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *w* | *AE* | *RE* | *RMSE* | *w* | *AE* | *RE* | *RMSE* | *w* | *AE* | *RE* | *RMSE* |
| LS | 12 | 4.2% | 6.4% | 3.44 | 24 | 5.4% | 9.5% | 6.10 | 24 | 12.3% | 890.0% | 24.66 |
| MLE | 12 | 3.1% | 4.6% | 2.49 | 12 | 4.8% | 8.2% | 4.71 | 96 | 7.6% | 391.3% | 10.92 |
| SA | 48 | 12.9% | 15.8% | 10.25 | 6 | 8.6% | 21.2% | 8.09 | 6 | 7.4% | 340.5% | 9.93 |
| TB ($c$=1) | 6 | 2.6% | 3.9% | 1.94 | 6 | 4.2% | 7.3% | 3.93 | 6 | 7.3% | 241.3% | 10.19 |
| TB ($c$=2) | 6 | 2.5% | 3.8% | 1.92 | 6 | 3.9% | 6.7% | 3.62 | 12 | 7.3% | 355.3% | 9.99 |
| TB ($c$=3) | 6 | 2.5% | 3.8% | 1.93 | 6 | 3.9% | 6.7% | 3.64 | 6 | 7.4% | 369.9% | 9.83 |

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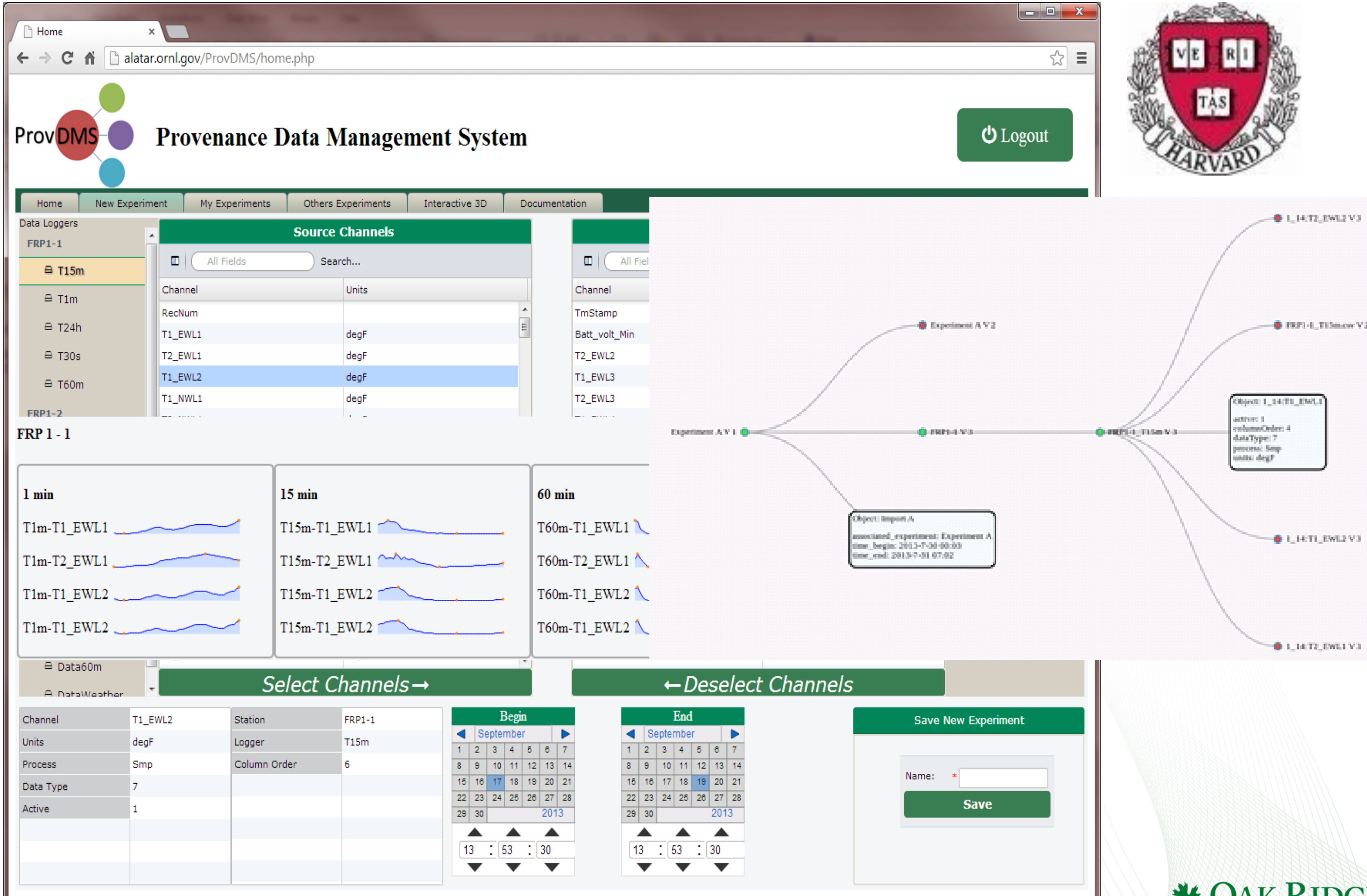
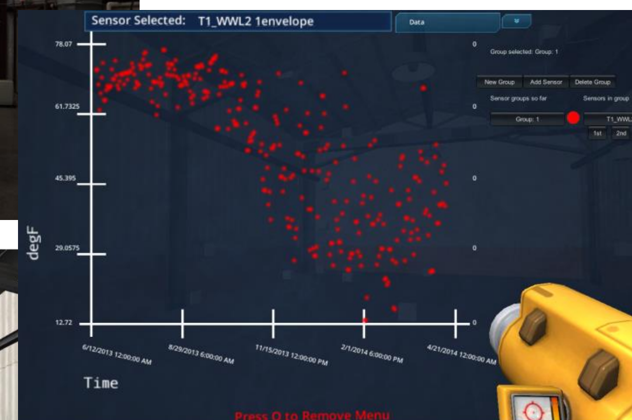
# Provenance – sensor lineage



# Unity Game for Sensor Data




# Presentation summary

- Scientific Paradigms
- Roof Savings Calculator
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- Autotune
- Saving Money





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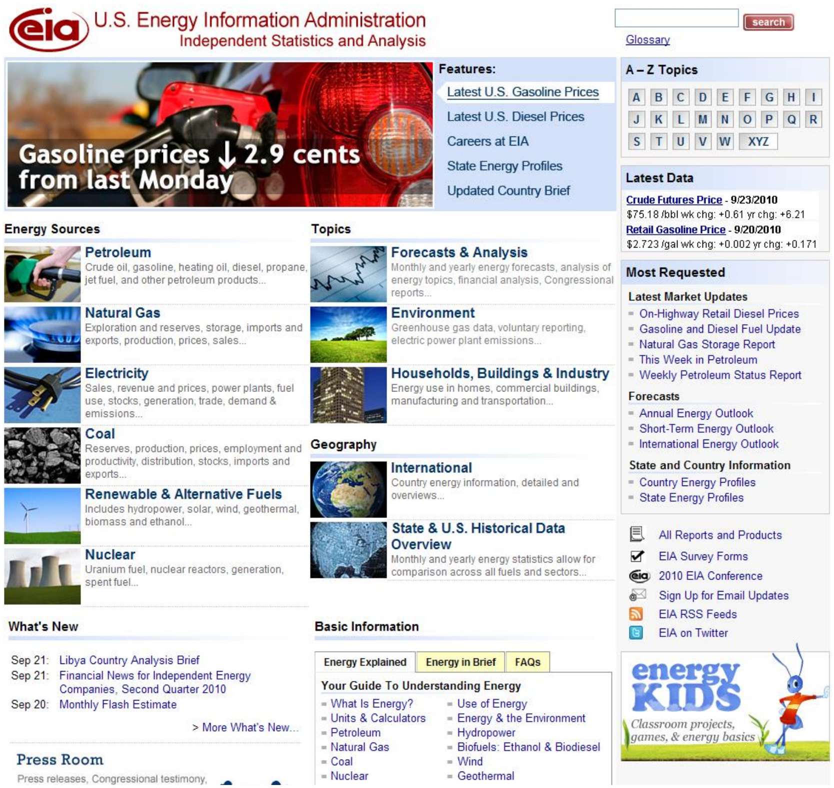
# Information Sources

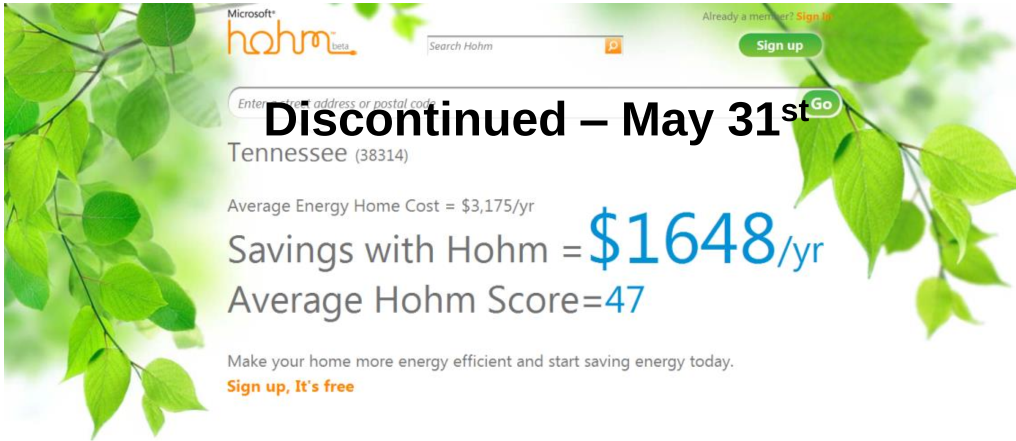



www.dsireusa.org/

# Scalability of utility data access

Discontinued


Discontinued – May 31st





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# Simulation for your home

Login | Help | About | Privacy | Media Room | Feedback

HOME ENERGY SAVER™ *pro*

Energy Assessment Tool for Home Professionals

START | DESCRIBE | COMPARE | UPGRADE | LEARN

SUMMARY | RECOMMENDATIONS | DETAILS

Building ID: Home
Location: Knoxville, Tennessee
Zip Code: 37934
Session: 2114321

**Potential Yearly Savings**

| | |
|---|---|
| Money: | $1,614 |
| Energy: | 18,357 kWh<br>0 Therms |
| Emissions: | 27,727 lb. $CO_2$ |

This reduction in greenhouse-gas emissions is like taking 2.4 car(s) off the road.

Will I make a difference?

Existing Home Configuration

You have visited 1 (4%) and completed 0 of the 23 possible forms.

# HESPro.lbl.gov

Print: This page | Report

## UPGRADE RECOMMENDATIONS

What efficiency level would you like to model for the initial selection of upgrades? EnergyStar

What simple payback period would you like to use for selecting upgrades? 10

RECALCULATE

Rows that are dimmed are not included in the calculated values for the retrofit package. To include them check their boxes and recalculate.

| Add/ Remove | Upgrade | Upgrade Choice & Description | Yearly Savings | Estimated Added Cost | How Much is Too Much? | Simple Payback Time | Estimated Return on Investment | Avoided Emissions (lbs. $CO_2$) |
|---|---|---|---|---|---|---|---|---|
| ☐ | Check/Uncheck All Upgrades | **Total for Selected Upgrades:** | **$1,614** | **$5** | **$16,140** | **4** | **27%** | **27,727** |
| ☑ | Thermostat | ENERGY STAR-labeled progra | $150 | $ 320 | $1,500 | 2 | 47% | 2,568 |
| ☑ | Windows | 2-pane/solar-control low-E/argc | $278 | $ 648 | $2,780 | 2 | 43% | 4,779 |
| ☑ | Indoor lights | CFLs in high-use fixtures | $45 | $ 88 | $450 | 2 | 42% | 1,417 |
| ☑ | Clothes washer | MEF=1.42 WF=9.5 ENERGY : | $61 | $ 180 | $610 | 3 | 33% | 762 |
| ☑ | Wall insulation | R-11 wall + R-5 exterior foam s | $371 | $ 1183 | $3,710 | 3 | 31% | 6,376 |
| ☑ | Duct Sealing | Reduce leakage to 6% of total | $263 | $ 890 | $2,630 | 3 | 29% | 4,520 |
| ☑ | Electric water heater | EF=0.95 | $45 | $ 195 | $450 | 4 | 22% | 767 |
| ☑ | Air sealing | 25% air leakage reduction | $157 | $ 850 | $1,570 | 5 | 18% | 2,701 |
| ☑ | Floor insulation | R-25 | $274 | $ 1534 | $2,740 | 6 | 18% | 4,697 |
| ☐ | Heat pump | SEER=14 HSPF=8.2 ENERGY | $66 | $ 739 | $660 | 11 | 1% | 1,136 |
| ☐ | Attic insulation | R-49 | $204 | $ 2615 | $2,040 | 13 | 7% | 3,498 |
| ☐ | Refrigerator | 15% better than standard ENE | $6 | $ 87 | $60 | 14 | 6% | 110 |
| ☐ | Duct Insulation | R-6 | $53 | $ 910 | $530 | 17 | NCE | 918 |
| ☐ | Dishwasher | EF=0.58 ENERGY STAR | $20 | $ 360 | $200 | 18 | NCE | 307 |

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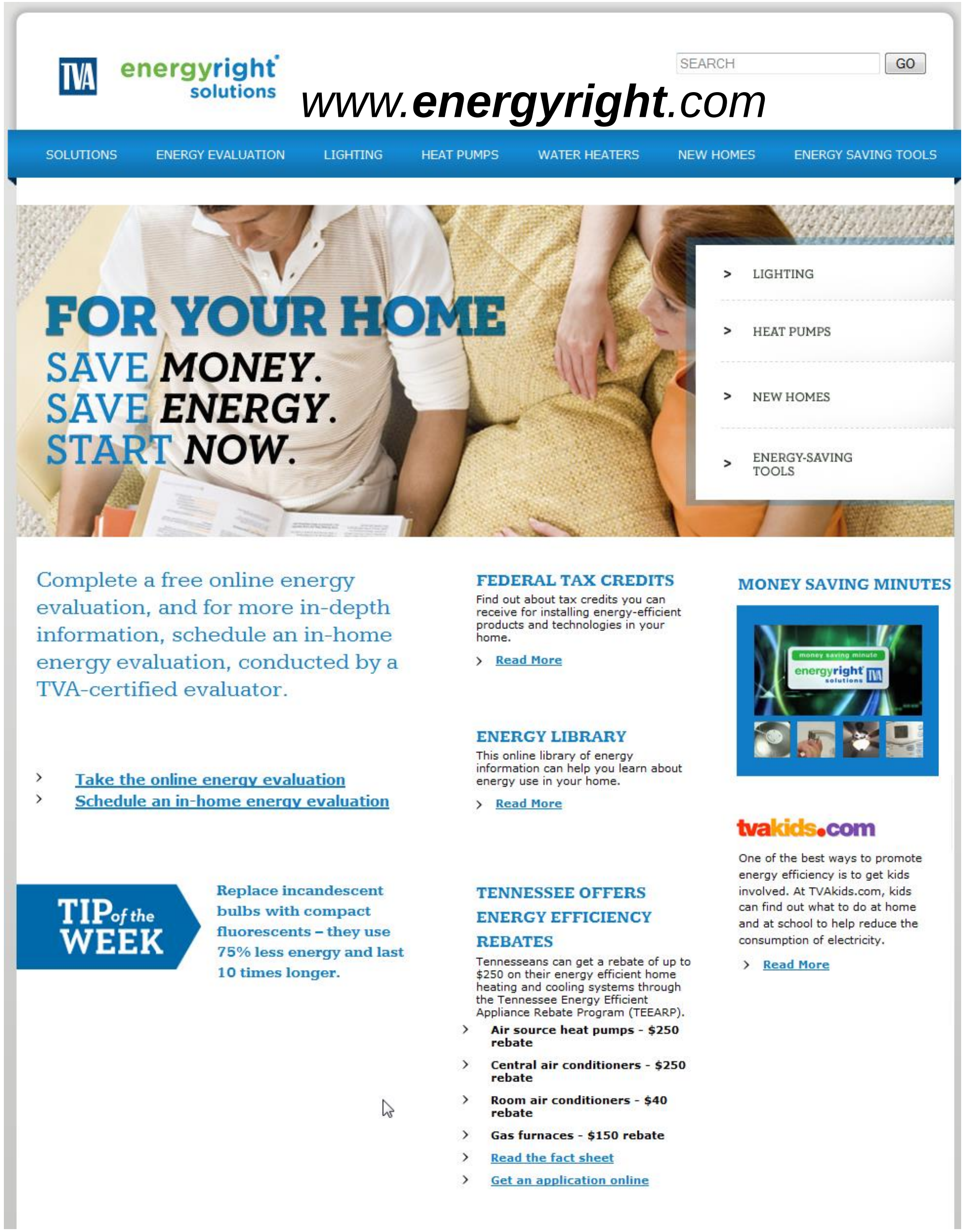
# Money for homeowners




You pay $150 for energy audit

Auditor provides list of recommendations

You pay up to $1000 for subset of recommendations

TVA give you $650 (reimburses $150 fee and pays 50% of cost up to $500)

# Discussion

Oak Ridge National Laboratory
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ETSD – Johney Green
BTRIC – Patrick Hughes
WBCI – Melissa Lapsa

Joshua New, Ph.D.
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