Visualization and Software Simulations for Actualized Energy Savings

ASHRAE Local Chapter
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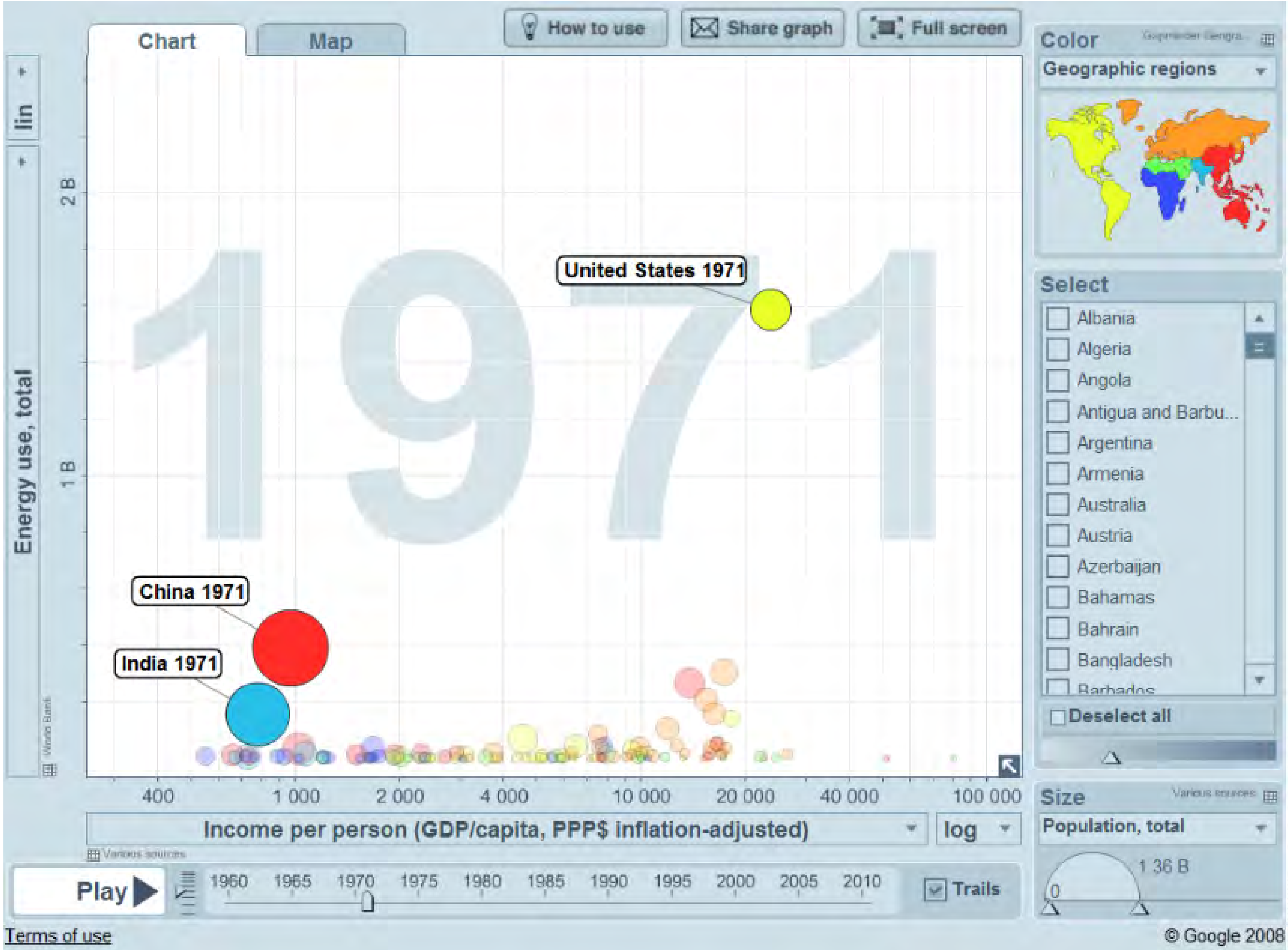
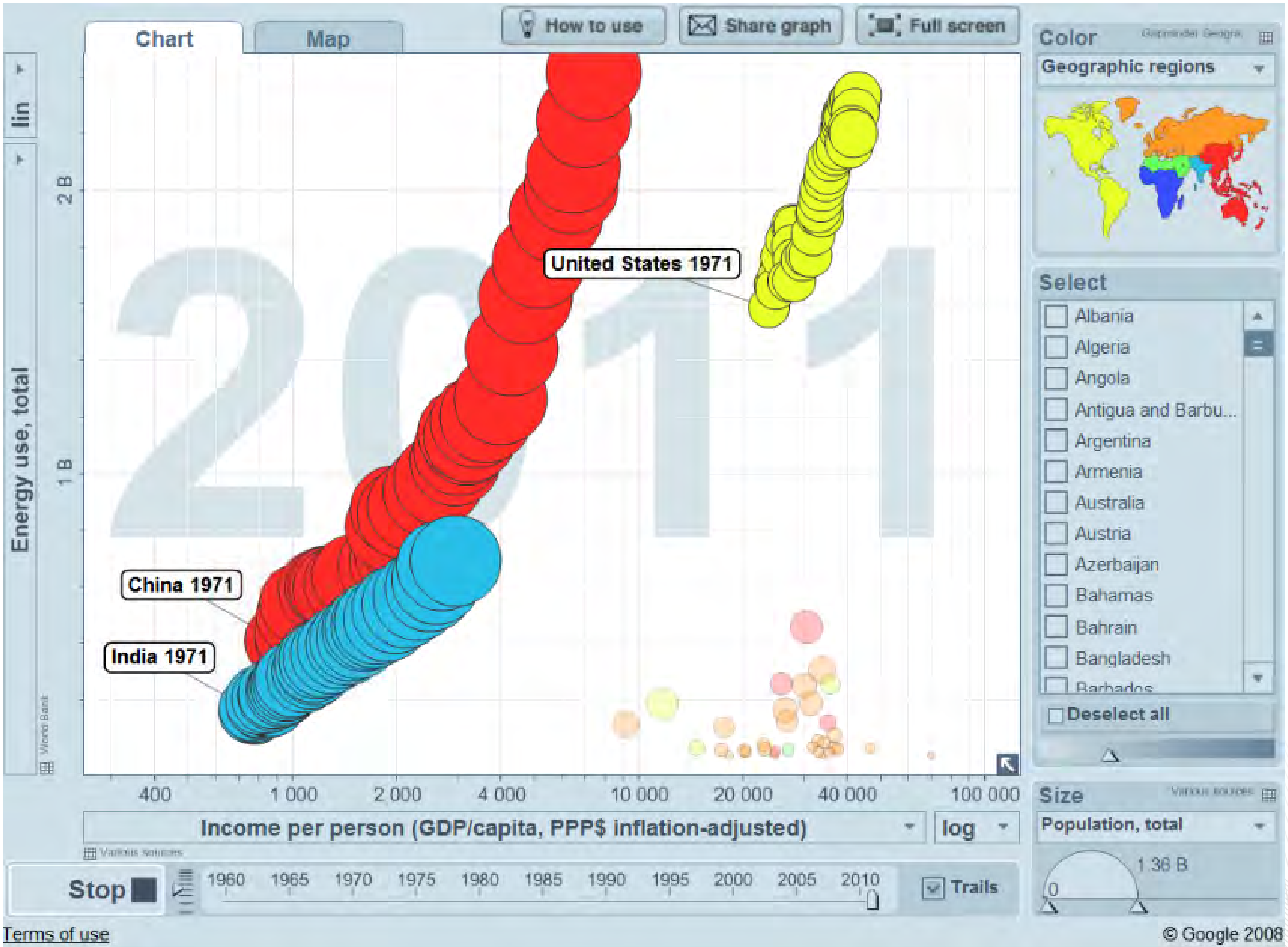
National Laboratory

40 Years: Energy and Quality of Life

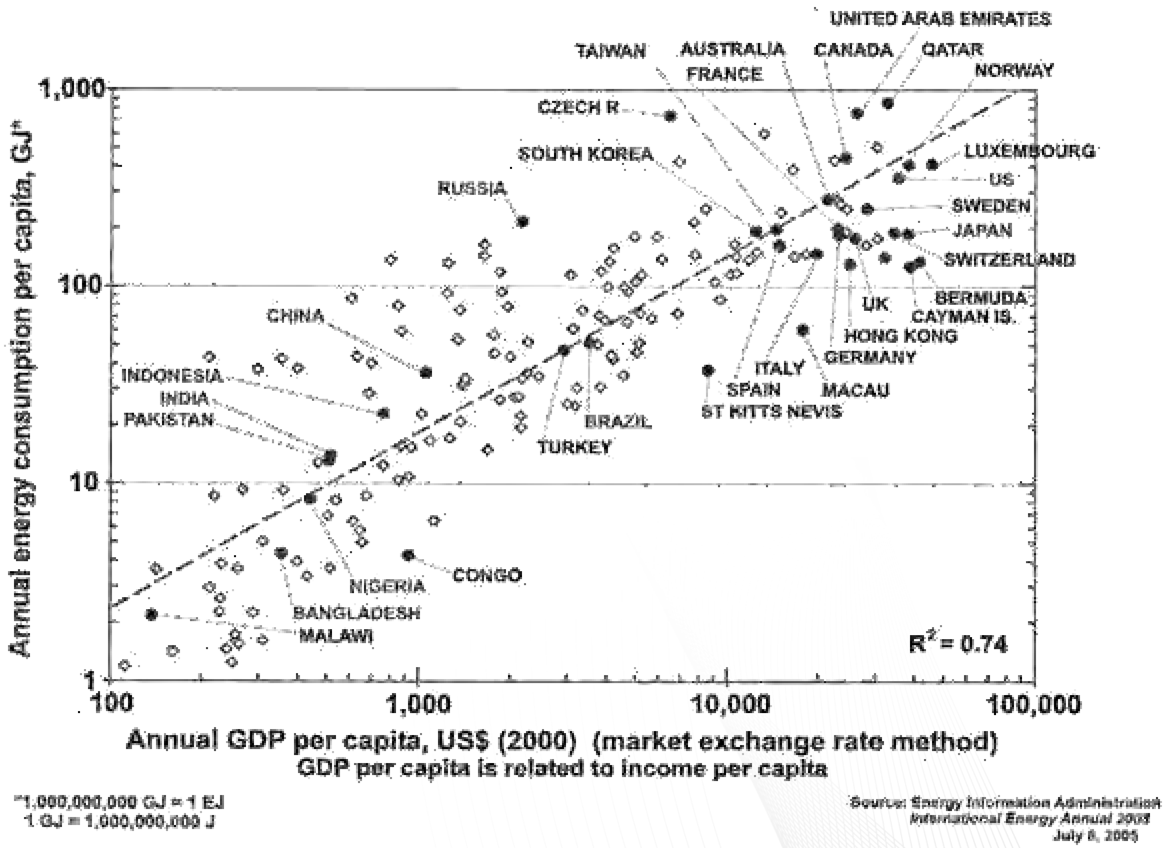


A brief history of energy and life quality

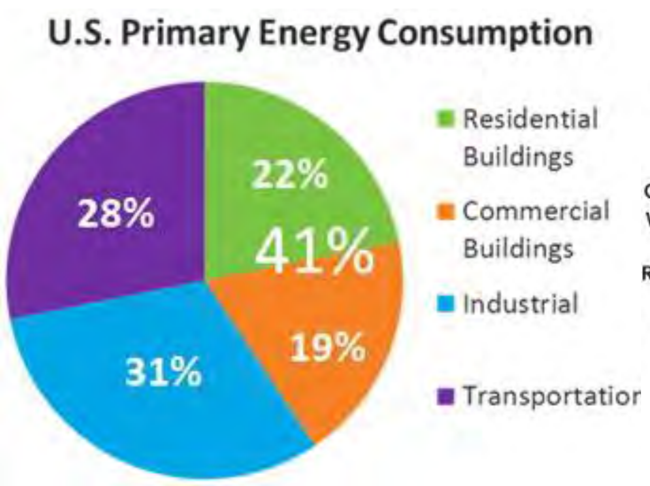


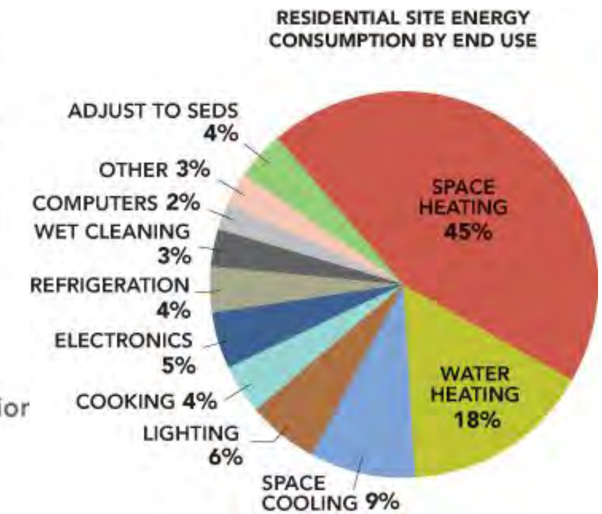
Sustainability is the defining challenge

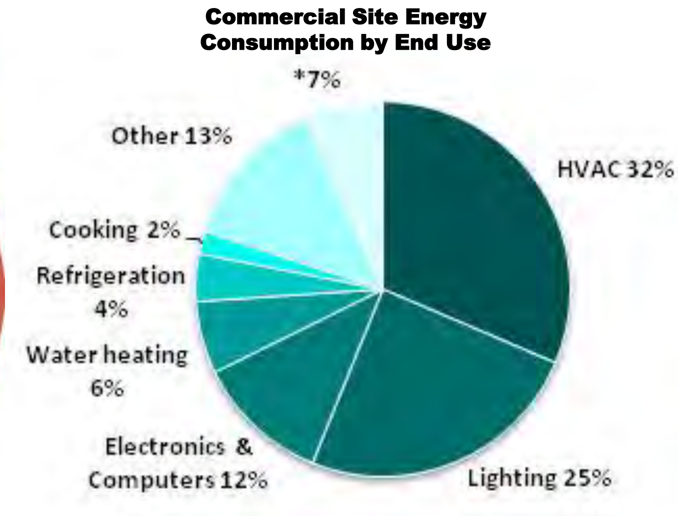
- Buildings in U.S.
  - 41% of primary energy/carbon 73% of electricity, 34% of gas
- Buildings in China
  - 60% of urban building floor space in 2030 has yet to be built
- Buildings in India
  - 67% of all building floor space in 2030 has yet to be built



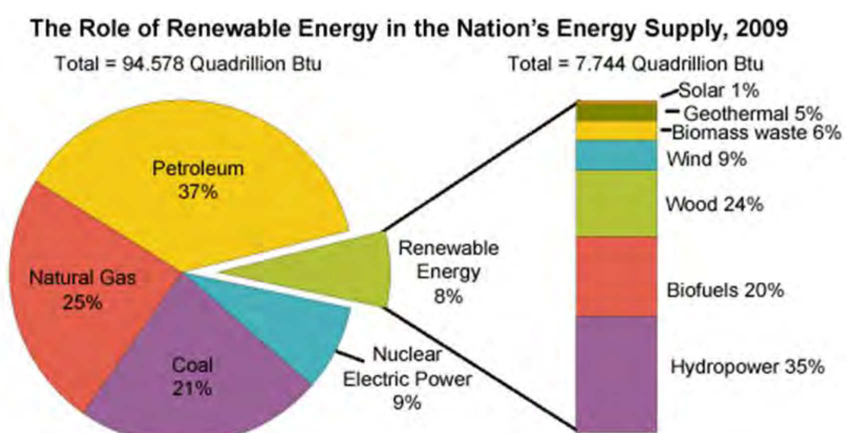
Energy Consumption and Production



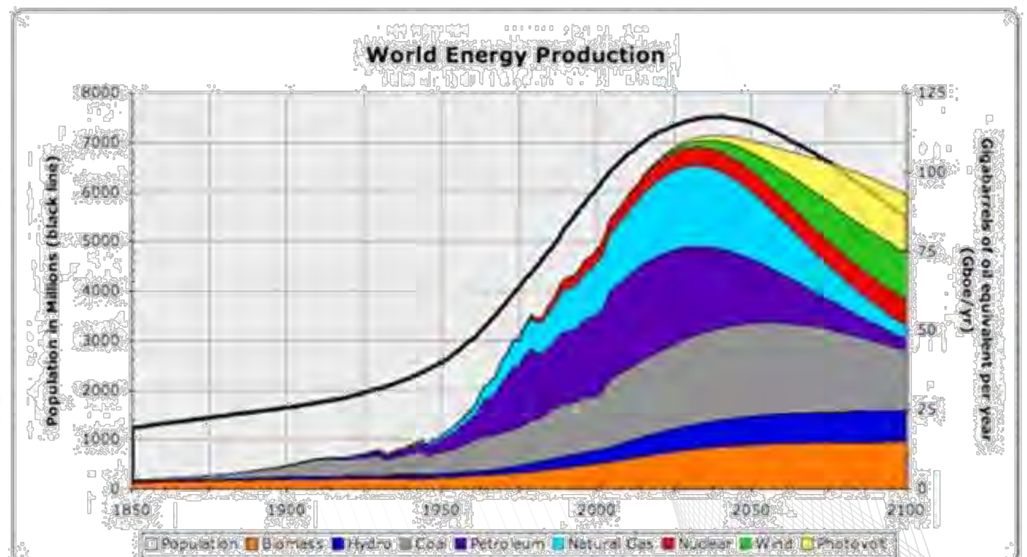




TN 2012 Electric Bill - $1,533



Note: Sum of components may not equal 100% due to independent rounding.
Source: U.S. Energy Information Administration, *Annual Energy Review 2009*, Table 1.3, Primary Energy Consumption by Energy Source, 1949-2009 (August 2010).



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Presentation summary

- Scientific Paradigms
- Roof Savings Calculator
- Visual Analytics
- Knowledge Work
- Autotune
- Publications

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Presentation summary

- Scientific Paradigms (context)
- Roof Savings Calculator
- Visual Analytics
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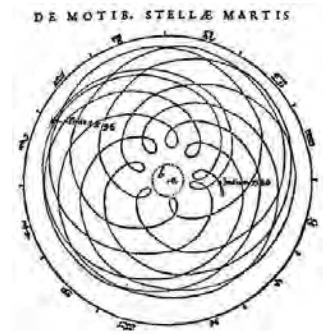
- Autotune
- Publications

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



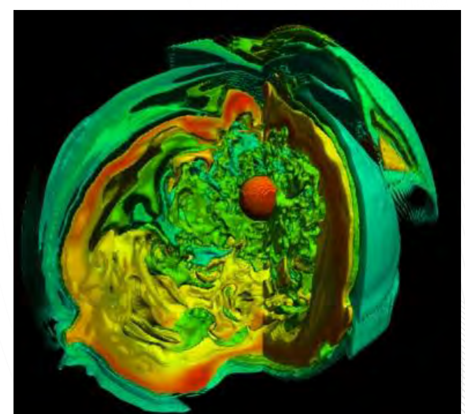
Johannes Kepler

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

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

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

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



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Presentation summary

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Urban Heat Island Effect and Albedo Engineering

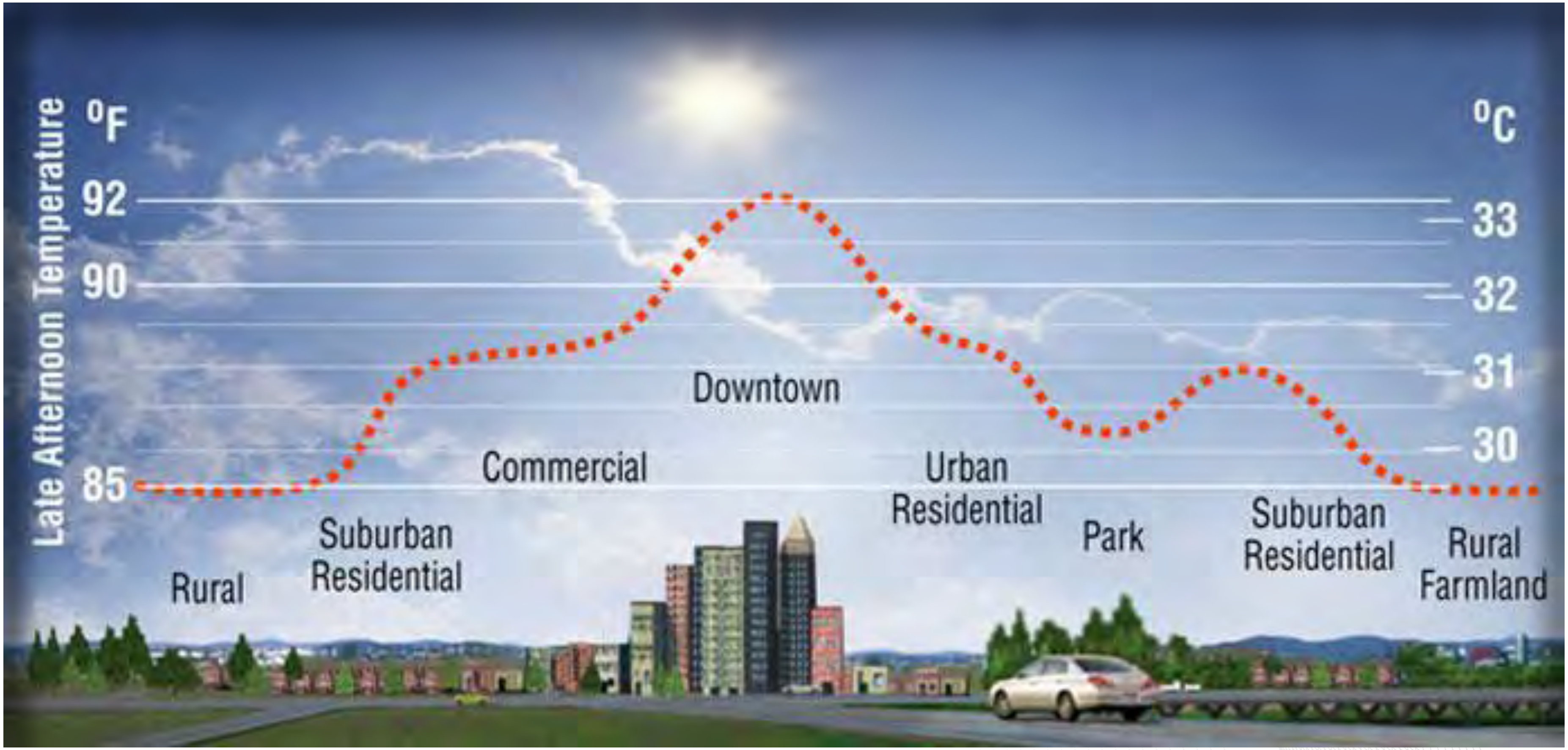
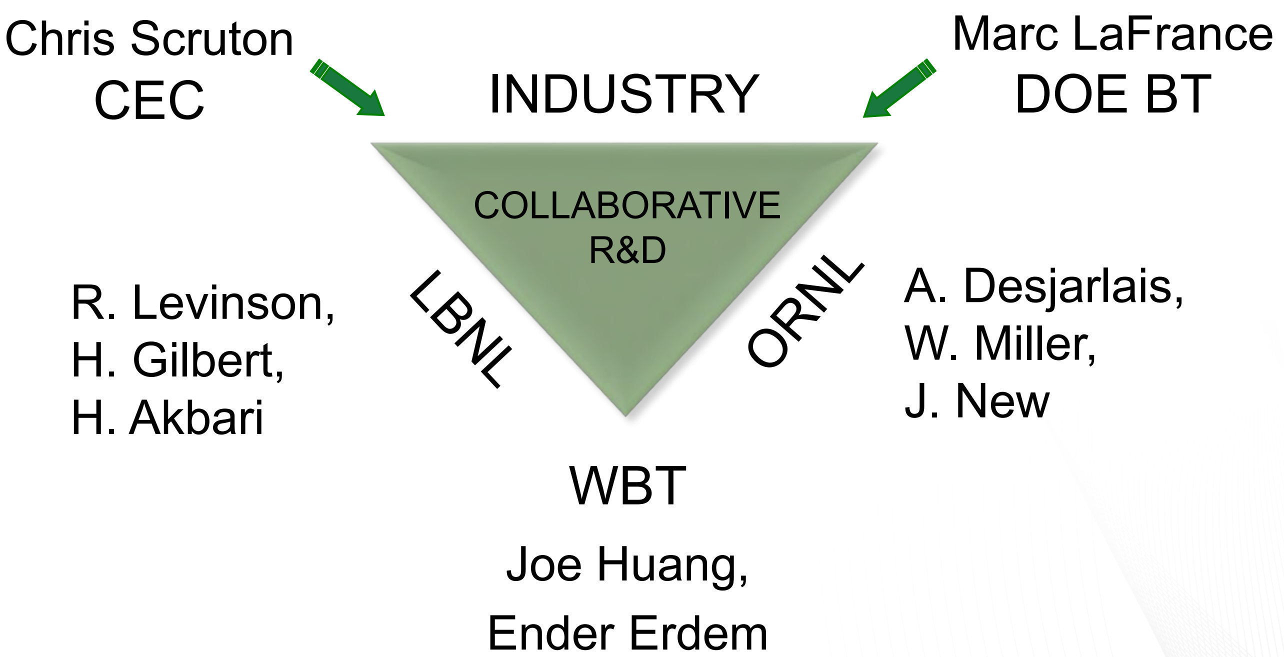


Image from Lawrence Berkeley National Laboratory

Computer tools for simulating cool roofs

Roof Savings Calculator (RSC)



Roof Savings Calculator

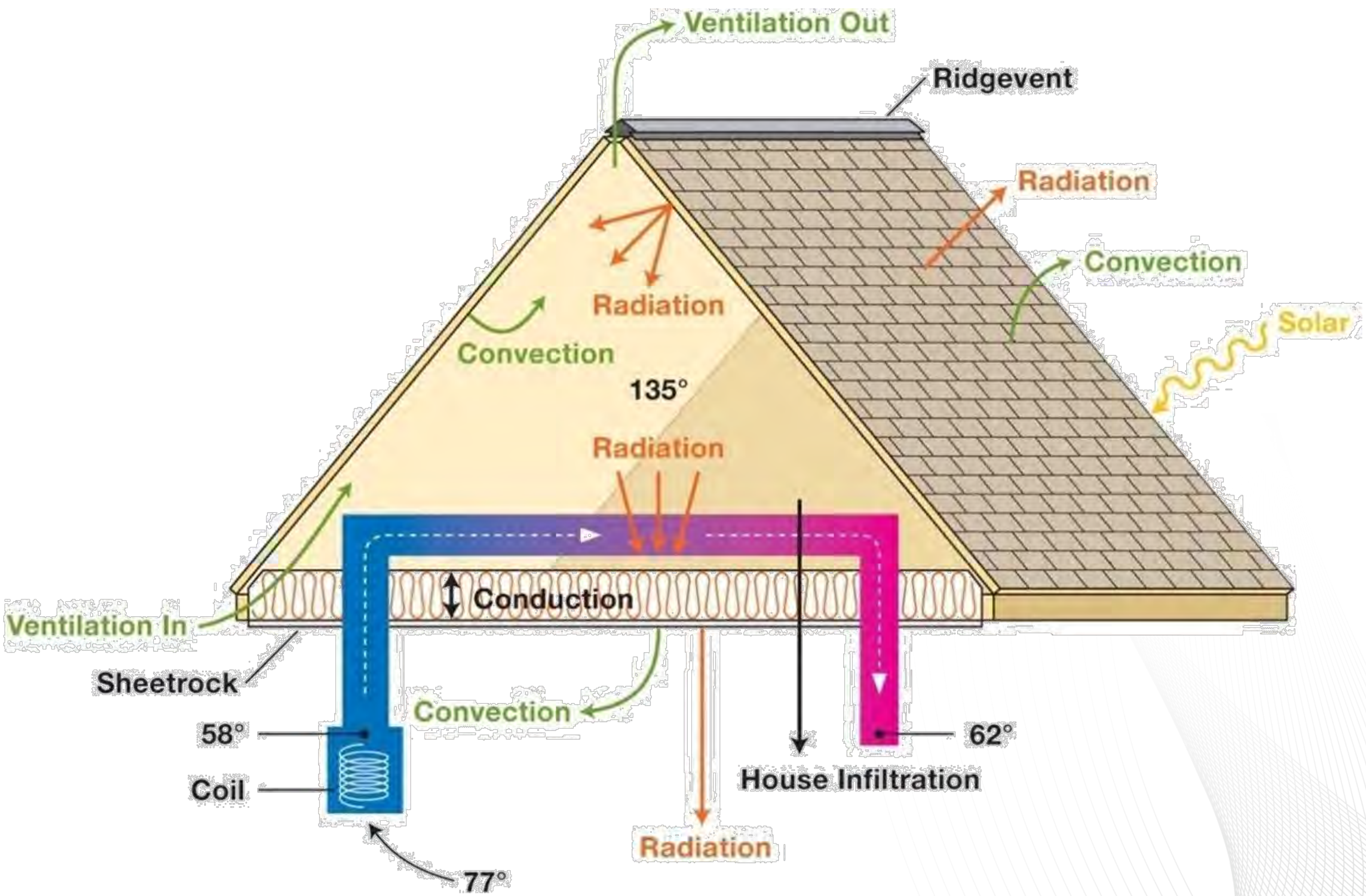
- Replaces:
  - EPA Roof Comparison Calc
  - DOE Cool Roof Calculator
- Minimal questions (<20)
  - Only location is required
  - Building America defaults
  - Help links for unknown information

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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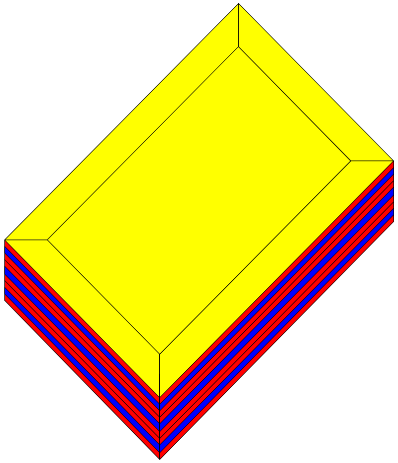
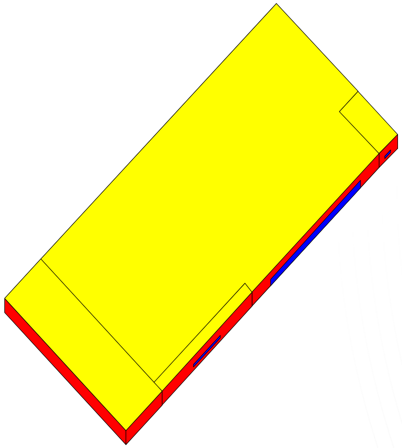
Commercial building types

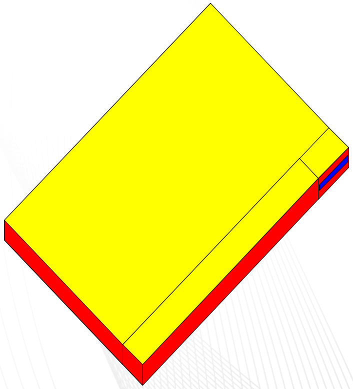
Office



"Big Box" Retail



Warehouse



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

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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%

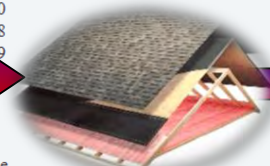
11. Thermal emittance (aged 3 yrs):
- ( ) Acrylic Al-Zn coated steel (15%)
- ( ) Bare Al-Zn coated steel (20%)
- ( ) Metallic field-applied coating (50%)
- ( ) Painted steel (85%)
- (•) Other materials (90%)

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-19
- ( ) 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
- ( ) 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

Energy Savings

Total	Cooling	Heating
$93	$95	-$2
1163 kWh	1189 kWh	-0.25 kWh

Monthly Savings

	[illegible]	[illegible]	Ma[illegible]	[illegible]	[illegible]	[illegible]	Jul	[illegible]	[illegible]	Oct	Nov	Dec
Avg Dry Temp (F)	27.6	[illegible]	[illegible]	51.4	64.7	70.5	76.1	71.8	[illegible]	[illegible]	43.3	34.5
Energy Savings (kWh)	-0.01	-0.2	[illegible]	26	24	210	308	239	210	[illegible]	[illegible]	13

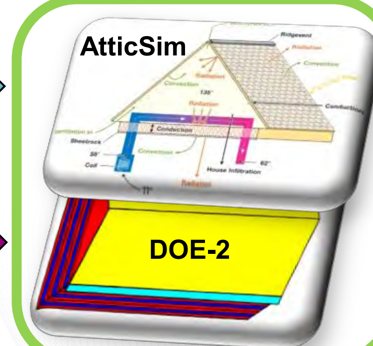
Retrofit Monthly Results

	Jan	[illegible]	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Heating (kWh)	387.166	[illegible]	[illegible]	55.04	8.676	.104	0	0.552	2.645	28.728	139.31	280.123
Cooling (kWh)	0	0	[illegible]	4.739	82.222	131.746	246.844	38.529	79.026	50.816	0	0

Base-Case Monthly Results

	Jan	Feb	[illegible]	Apr	May	Jun	Jul	Aug	[illegible]	Oct	Nov	Dec
Heating (kWh)	387.156	[illegible]	[illegible]	75.04	8.676	.104	0	0.552	[illegible]	[illegible]	139.31	280.123
Cooling (kWh)	0	0	[illegible]	5.739	128.222	261.746	454.844	337.529	183.026	[illegible]	0	0

Downloads:
Raw Input data
Raw Output data



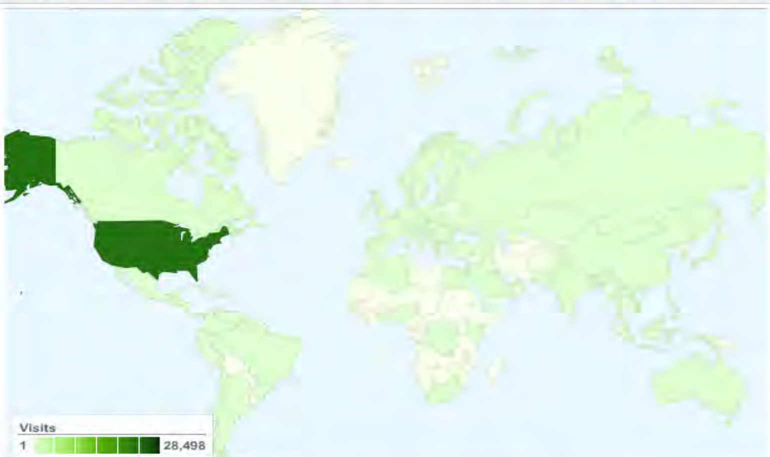
RoofCalc.com impact

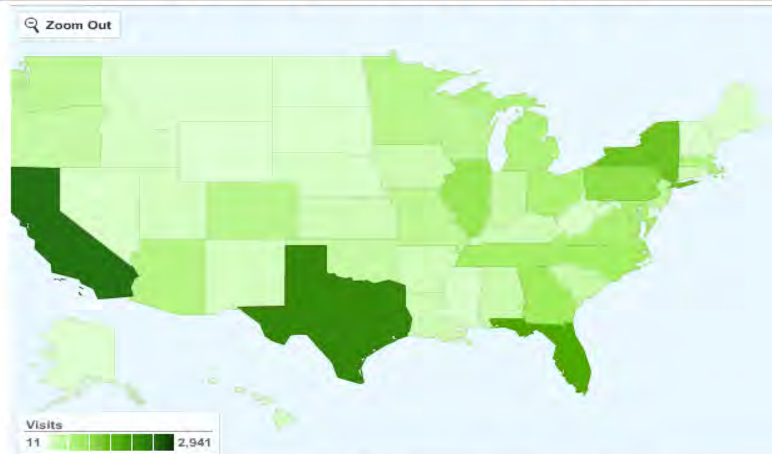
Dashboard

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	1.42	00:01:25	88.26%	70.34%
% of Site Total: 100.00%	Site Avg: 1.42 (0.00%)	Site Avg: 00:01:25 (0.00%)	Site Avg: 88.23% (0.04%)	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

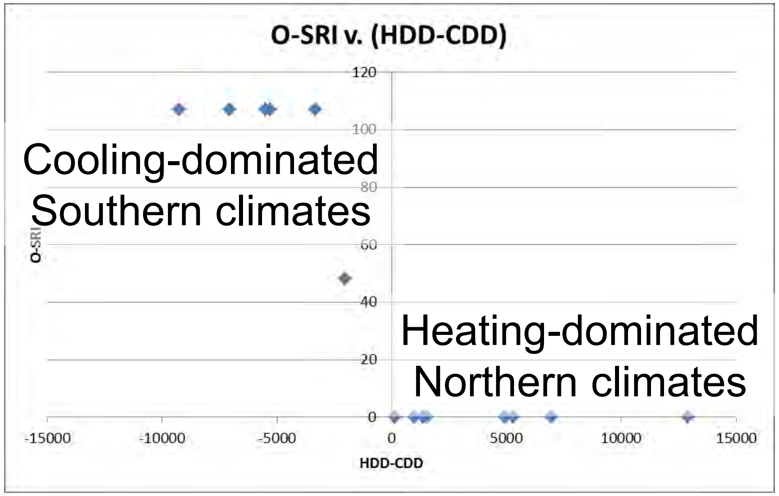
Visits	Pages/Visit	Avg. Time on Site	% New Visits	Bounce Rate
28,498	1.42	00:01:25	88.35%	70.34%
% of Site Total: 92.67%	Site Avg: 1.42 (-0.09%)	Site Avg: 00:01:25 (0.96%)	Site Avg: 88.23% (0.14%)	Site Avg: 70.34% (-0.00%)

	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	Reflect ance	Emis sivity	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.

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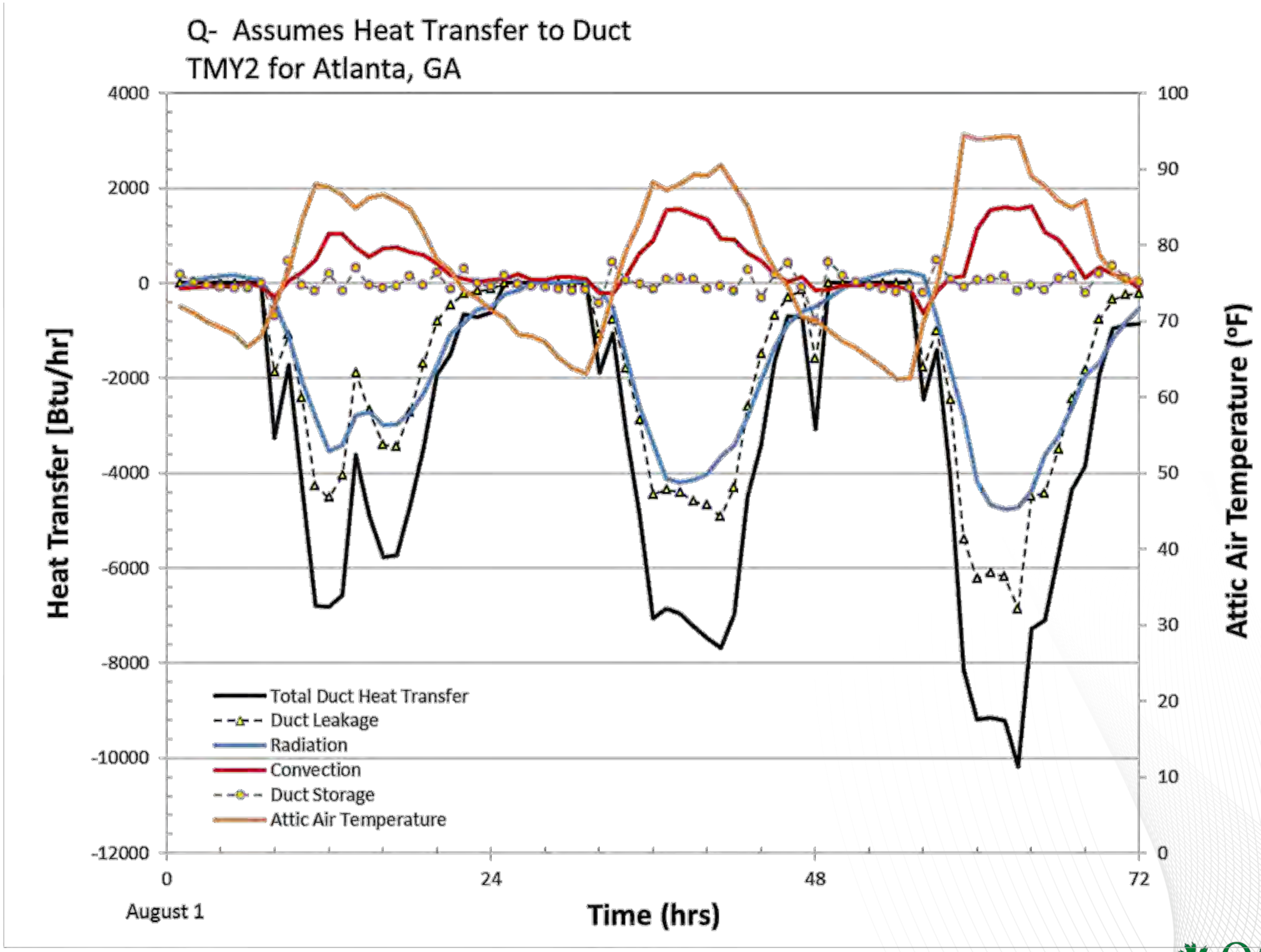
Summer operation of HVAC duct in ASHRAE climate zone 3



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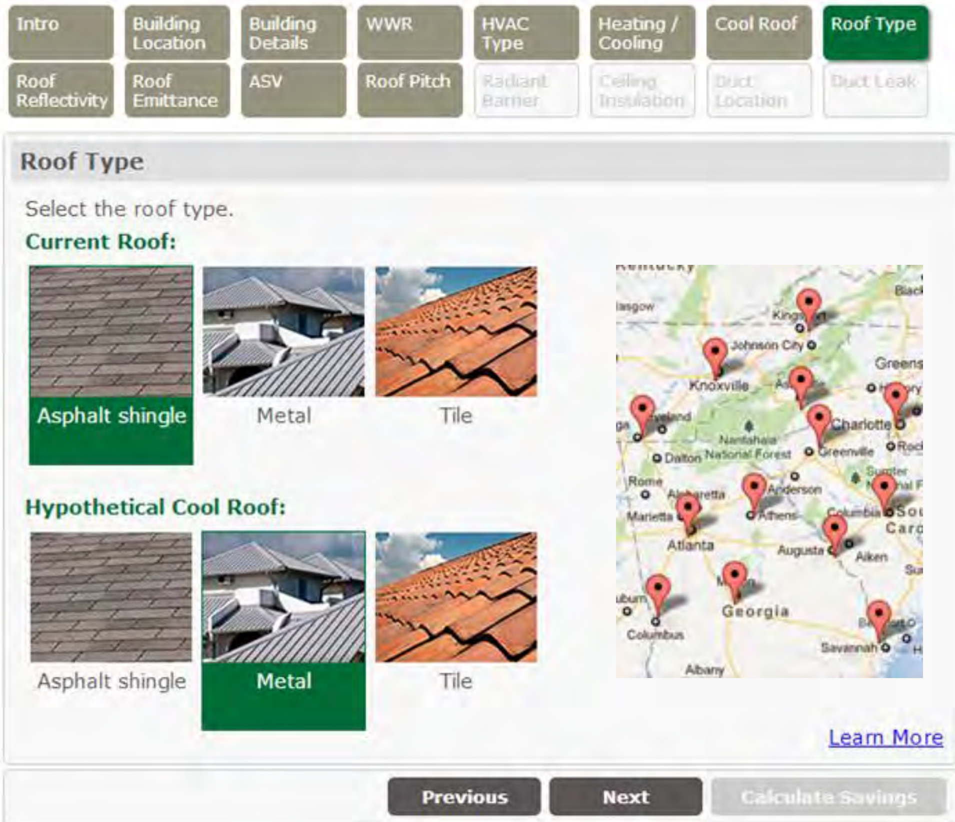
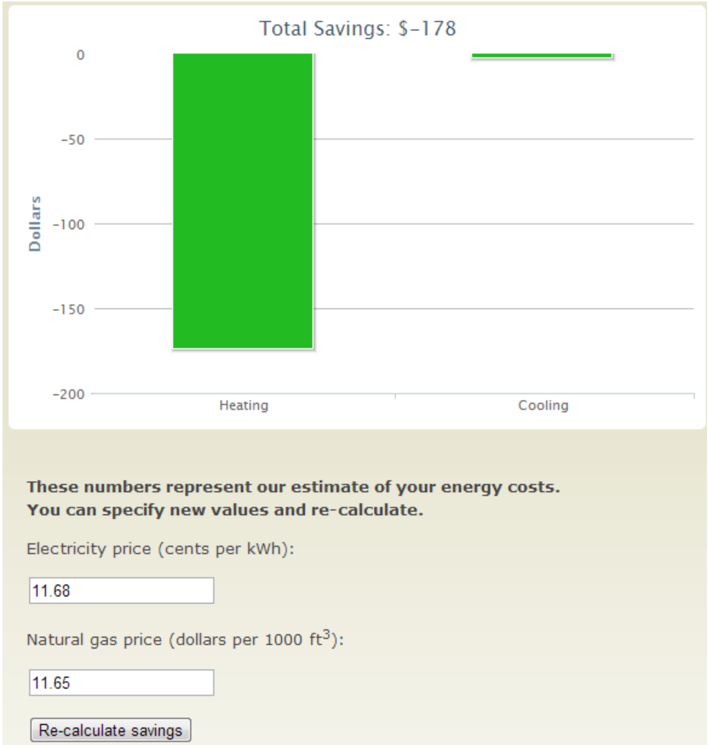
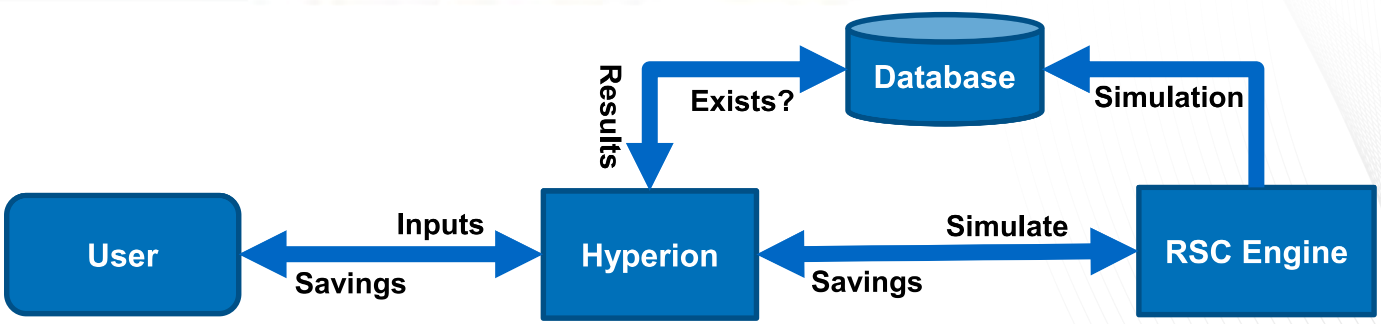
Enhanced RSC Site

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

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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

```python
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')
```


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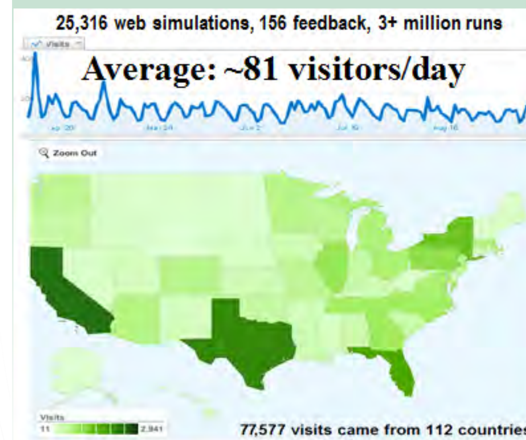
Millions of simulations visualized for DOE's Roof Savings Calculator and deployment of roof and attic technologies through leading industry partners

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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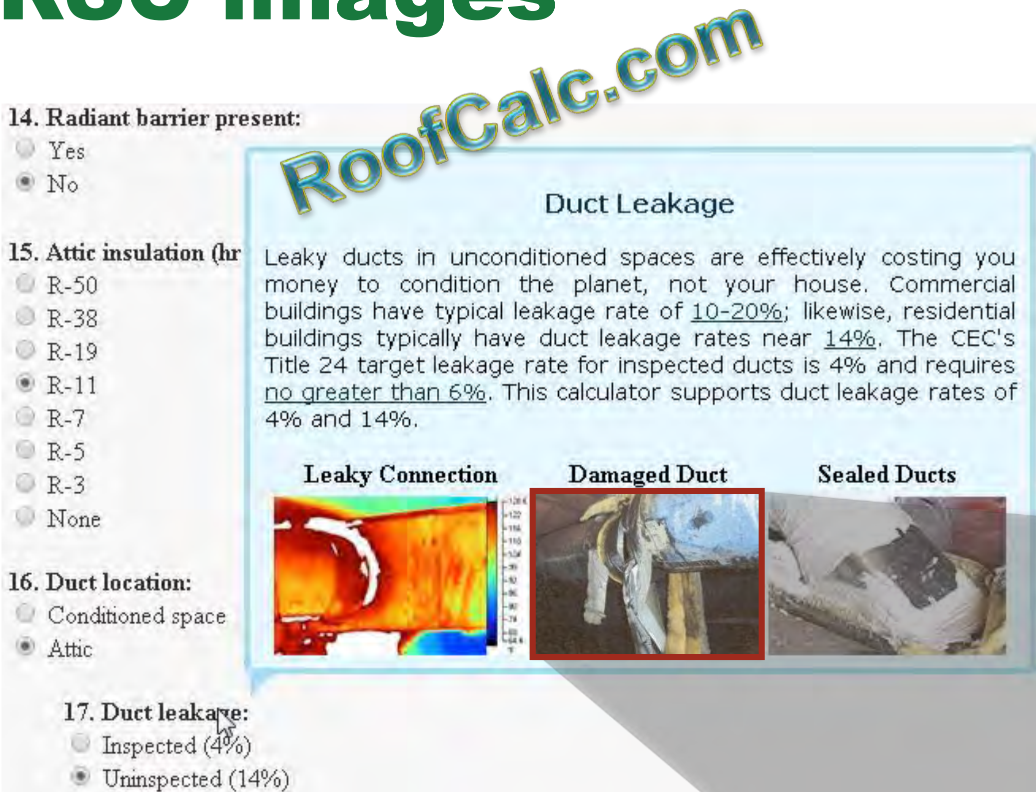
Personal story behind one of DOE's RSC images



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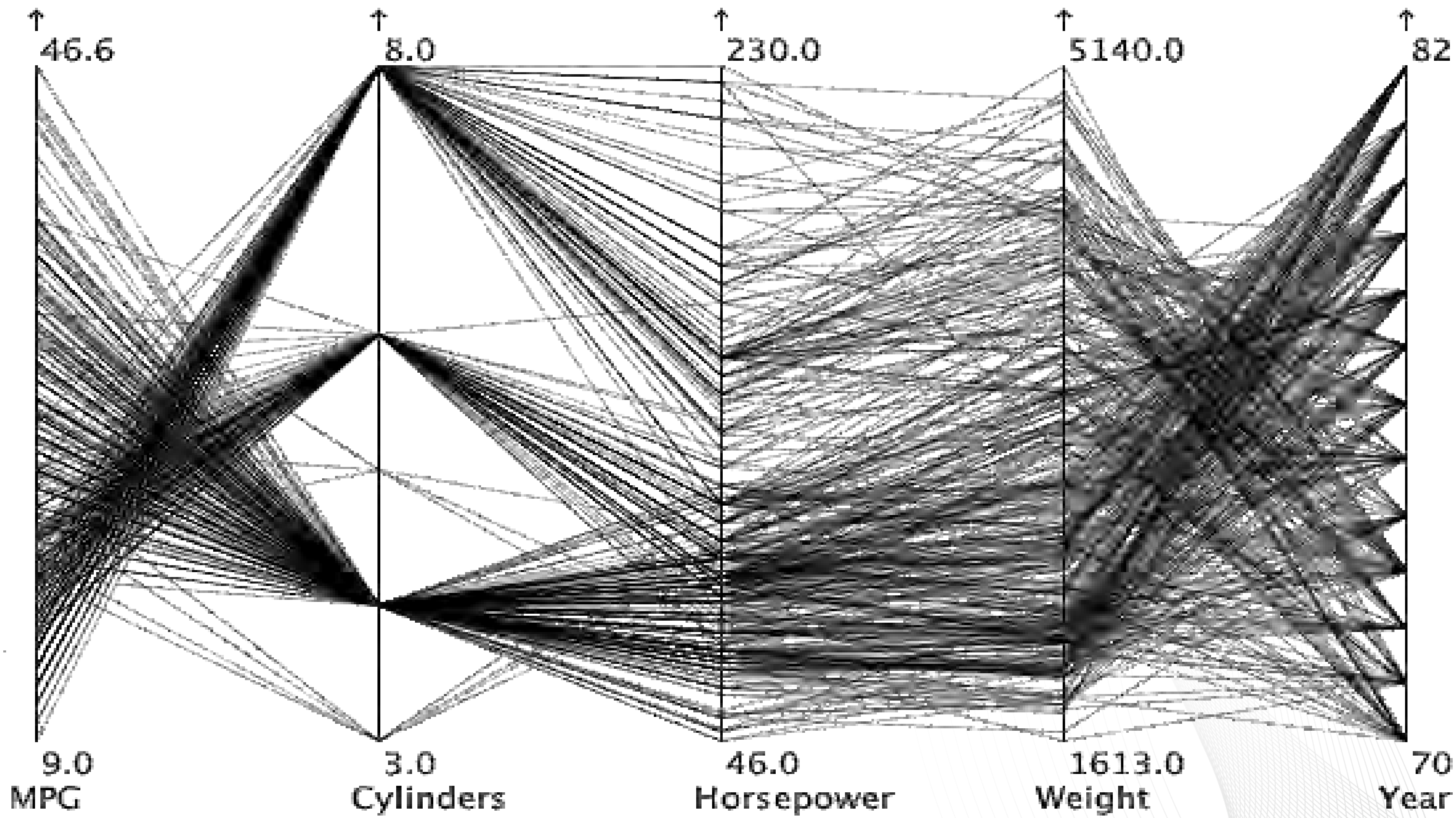
PCP - car data set



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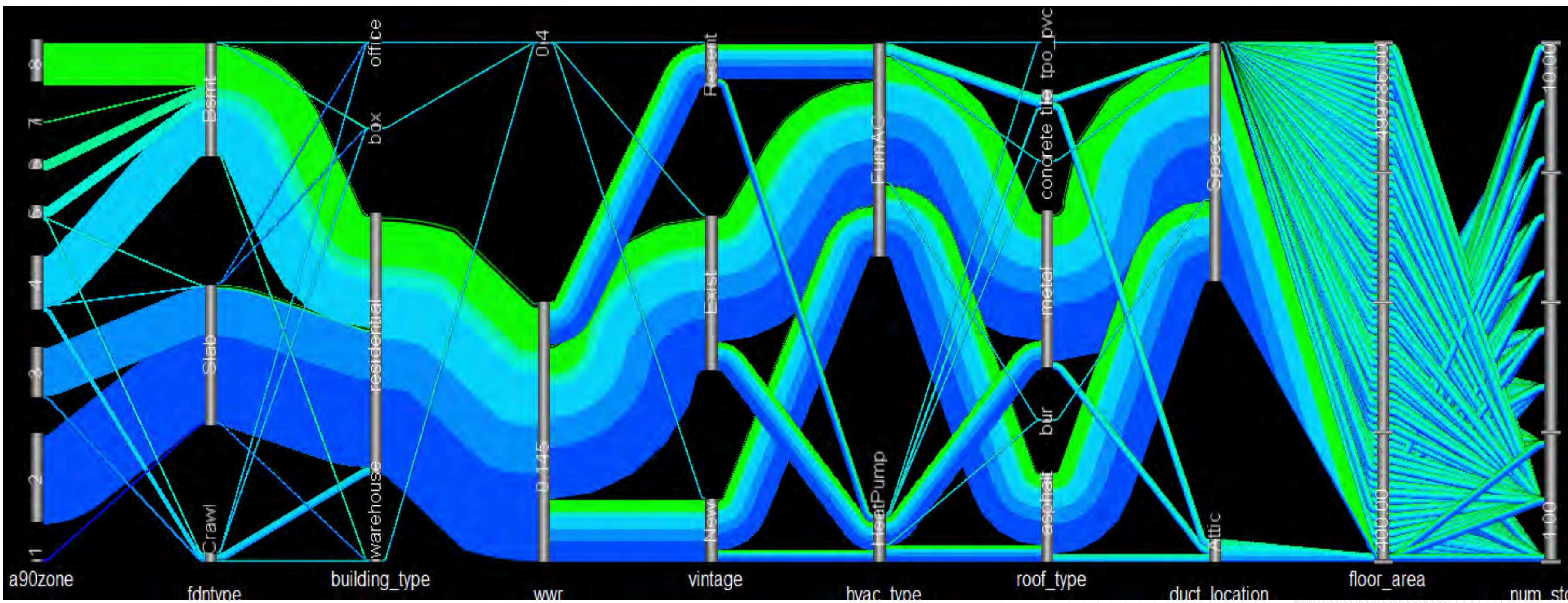
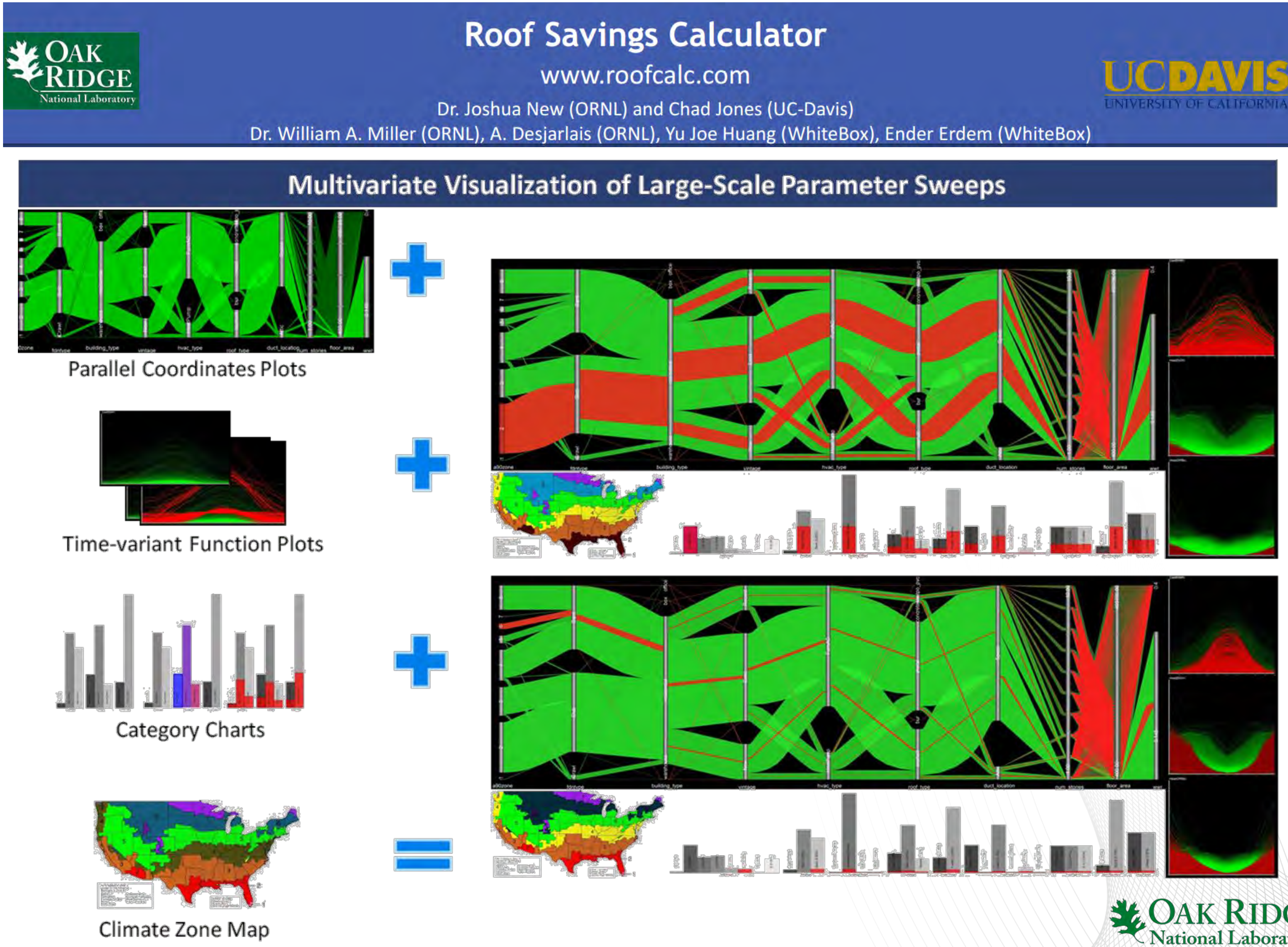
PCP bin rendering (data)

- Transfer function coloring:
  - Occupancy or leading axis



The power of "and" – linked views (info)



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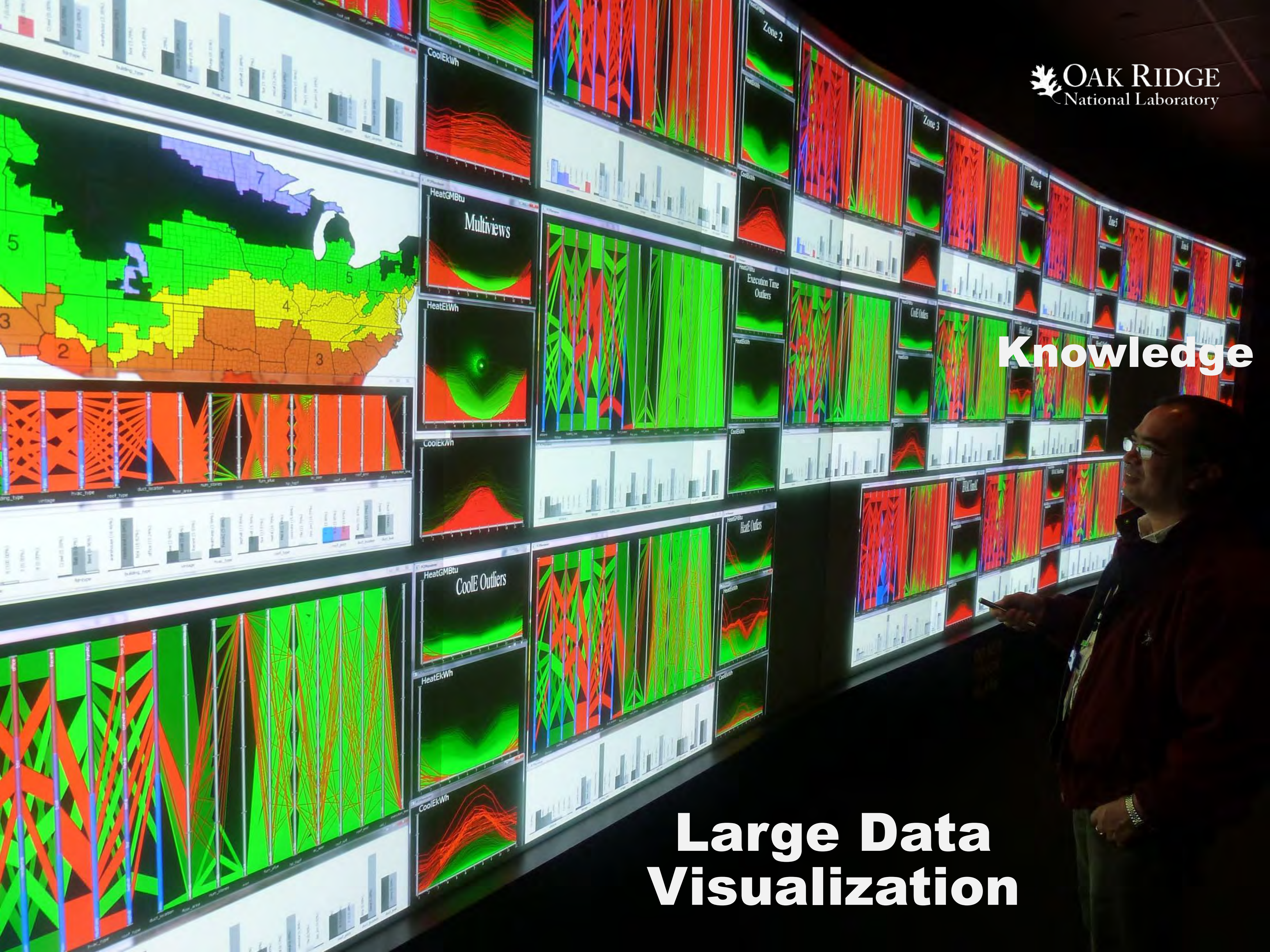
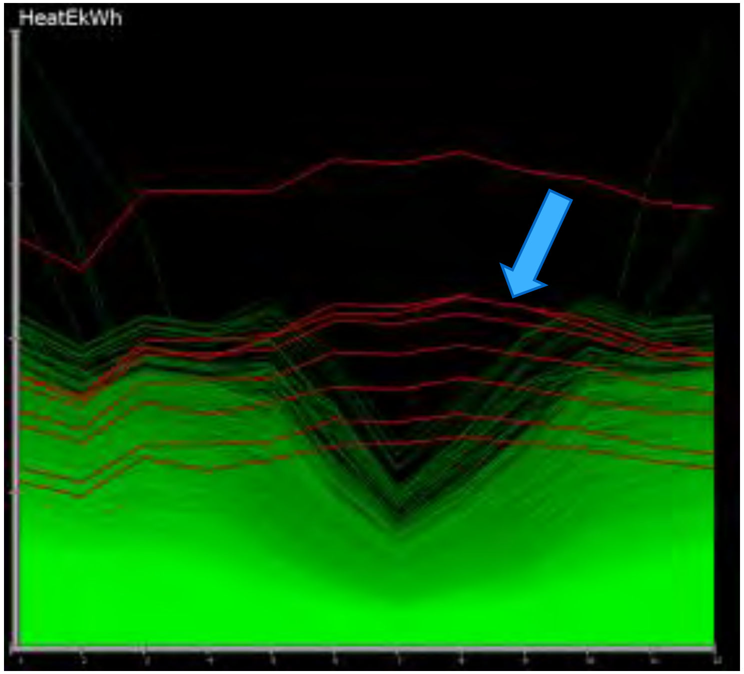
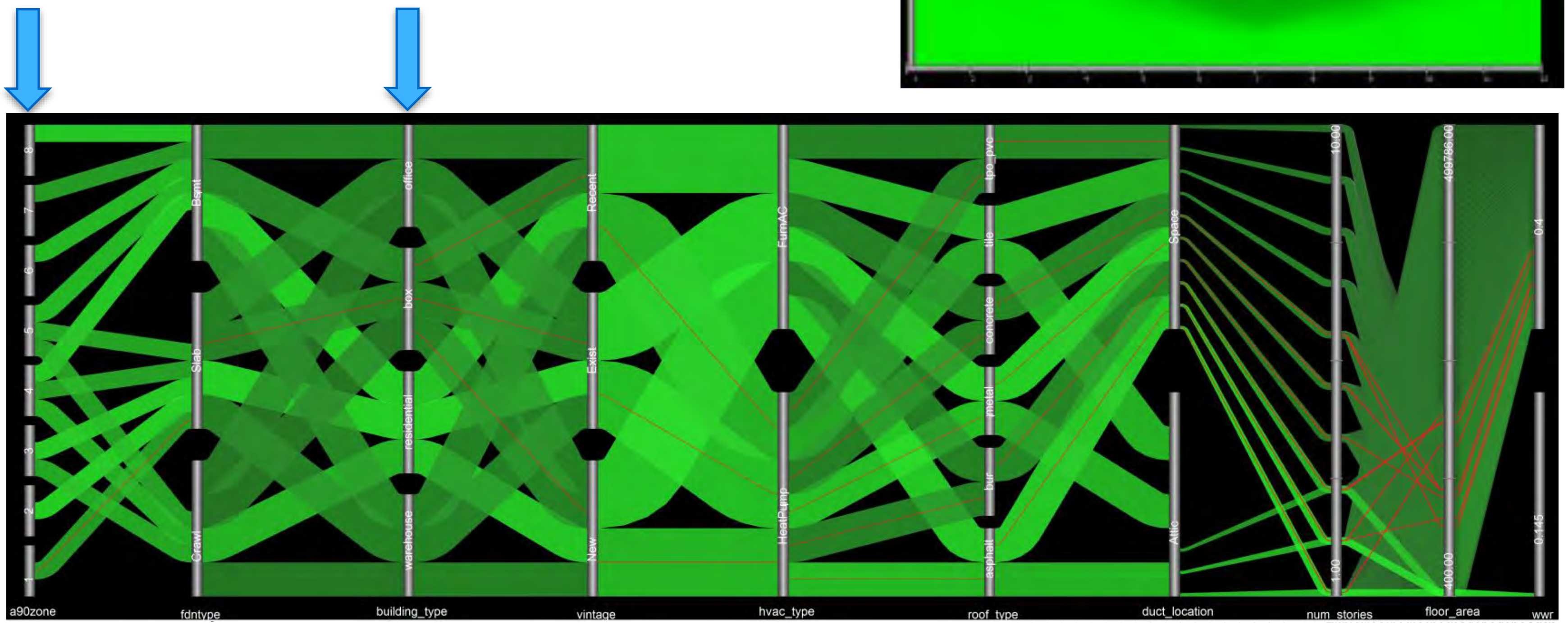

OAK RIDGE
National Laboratory
Knowledge
Large Data
Visualization
Multiviews
CoolE Outliers
Execution Time
Outliers
HeatE Outliers
Zone 2
Zone 3
HeatGMBtu
HeatEkWh
CoolEkWh

Outliers (wisdom)

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

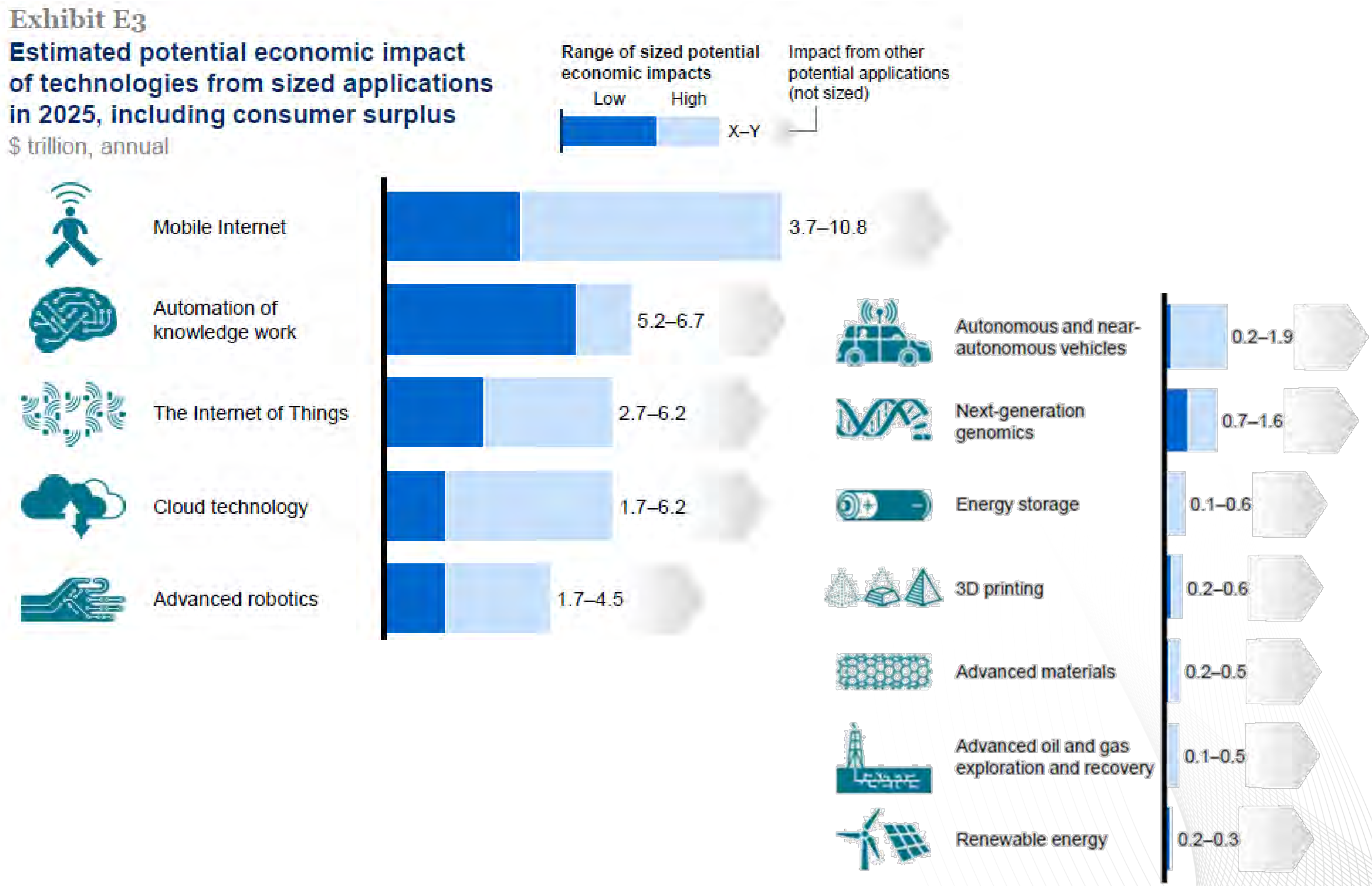




Presentation summary

- Scientific Paradigms
- Roof Savings Calculator
- Visual Analytics
- Knowledge Work (context)
- Autotune

McKinsey Global Institute Analysis



Source: McKinsey Global Institute analysis

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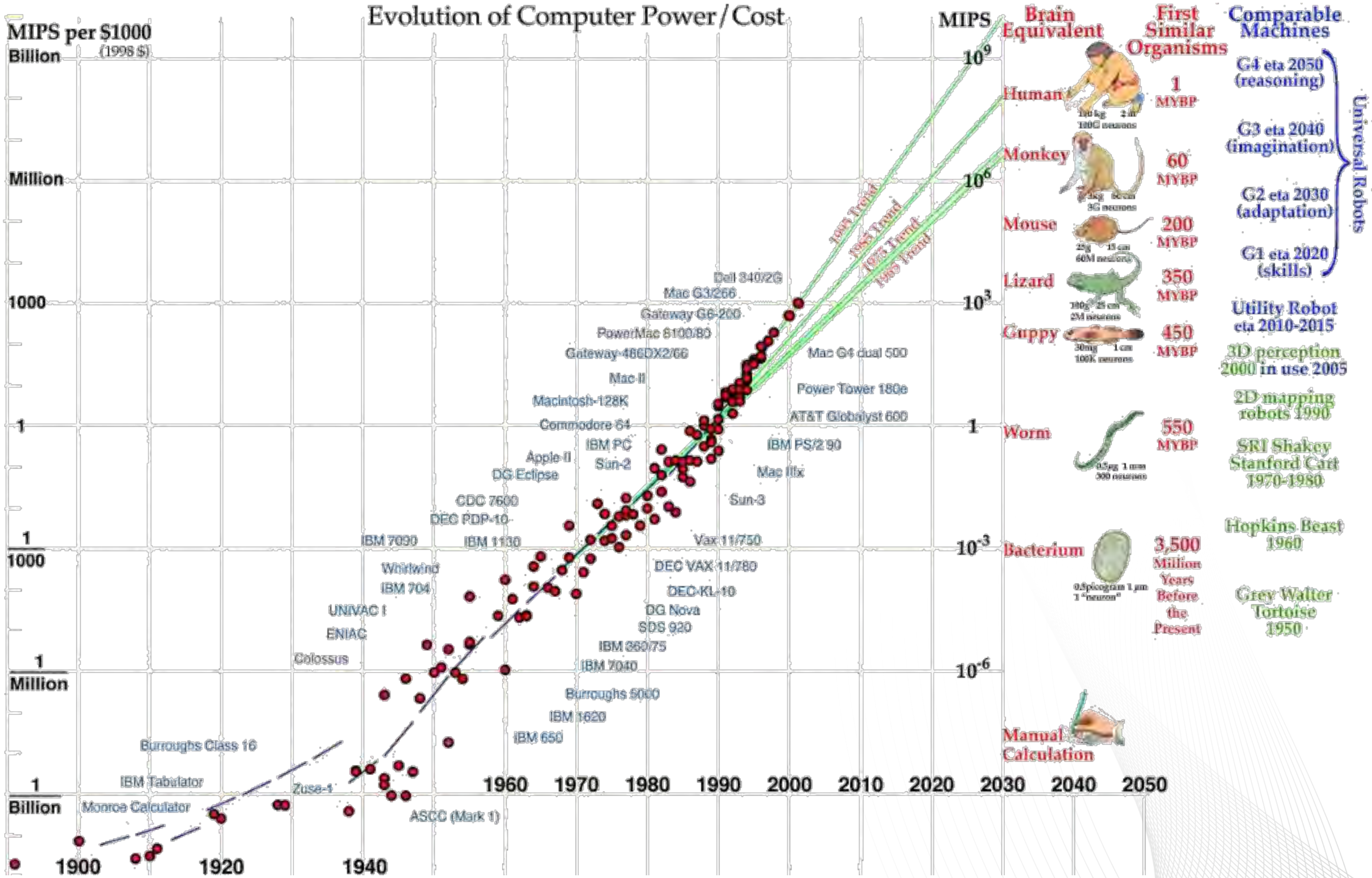
$1000 machine helping meat machines



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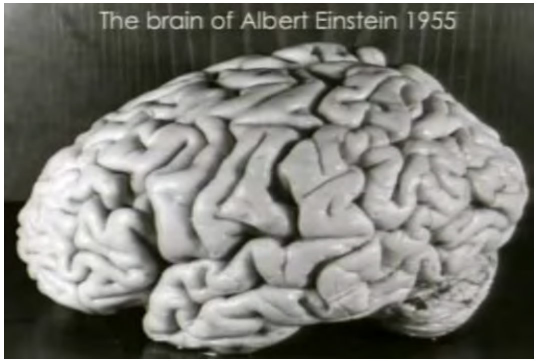
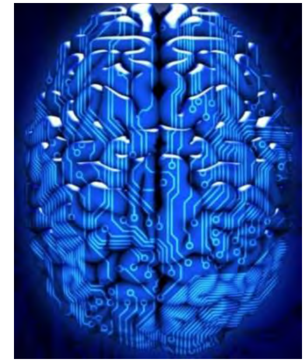
Humans and computers

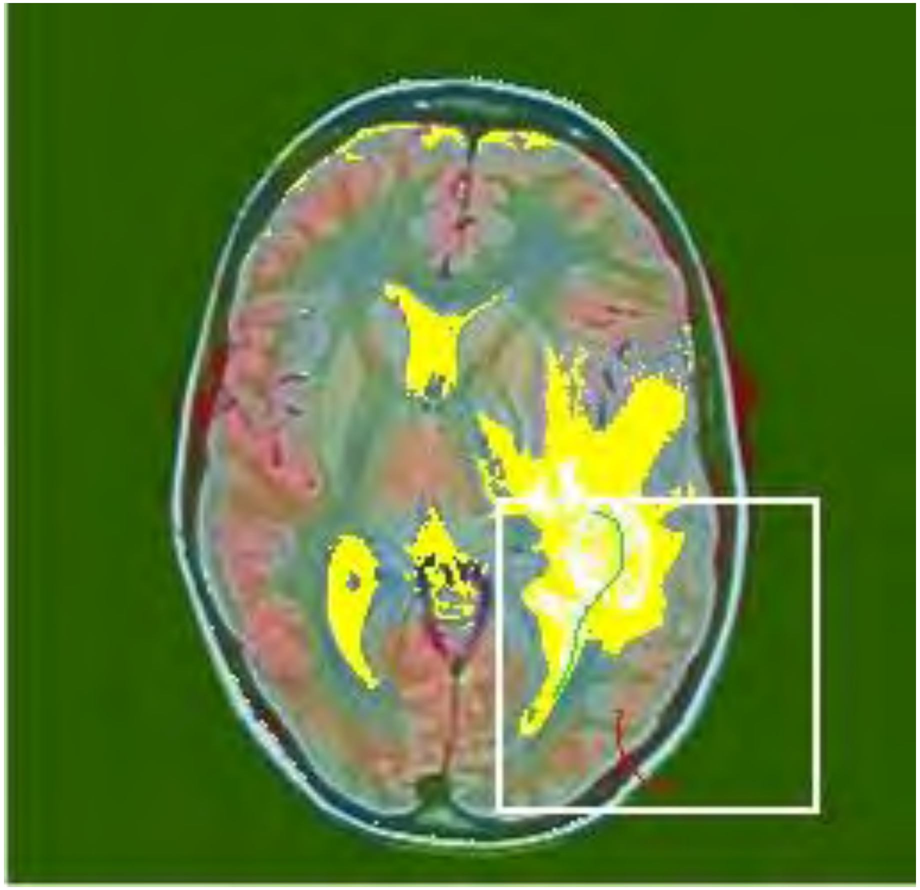


- 3 lbs (2%), 20 watts (20%)
- 120-150 billion neurons
- 100 trillion synapses
  - Firing time ~milliseconds
- 11 million bits/second input
  - Consciousness - 40 bits/second
- Working memory – 4-9 words
- Long-term memory – 1-1k TB
- Complex, self-organizing



- 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

Presentation summary

- Scientific Paradigms
- Roof Savings Calculator
- Visual Analytics
- Knowledge Work (context)
- Autotune

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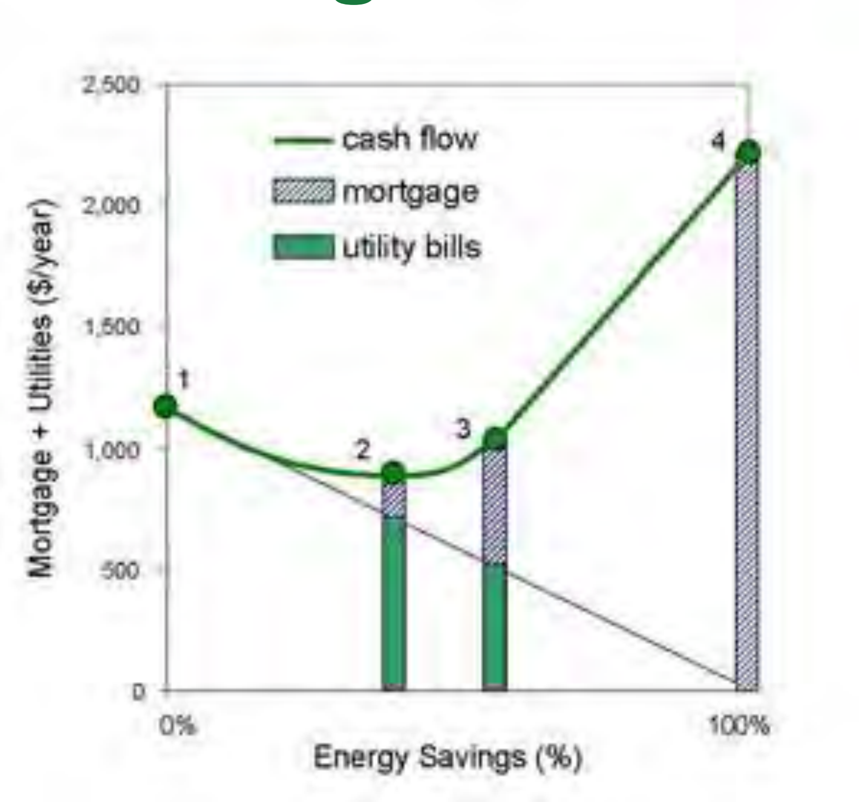
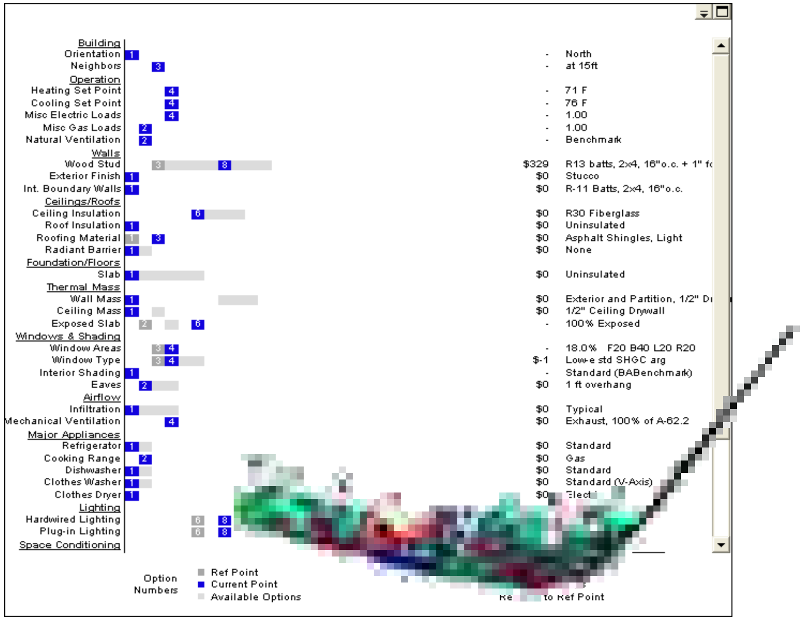
Existing tools for retrofit optimization





Simulation Engine
DOE–$65M (1995–?)

EnergyPlus

API

OpenStudio

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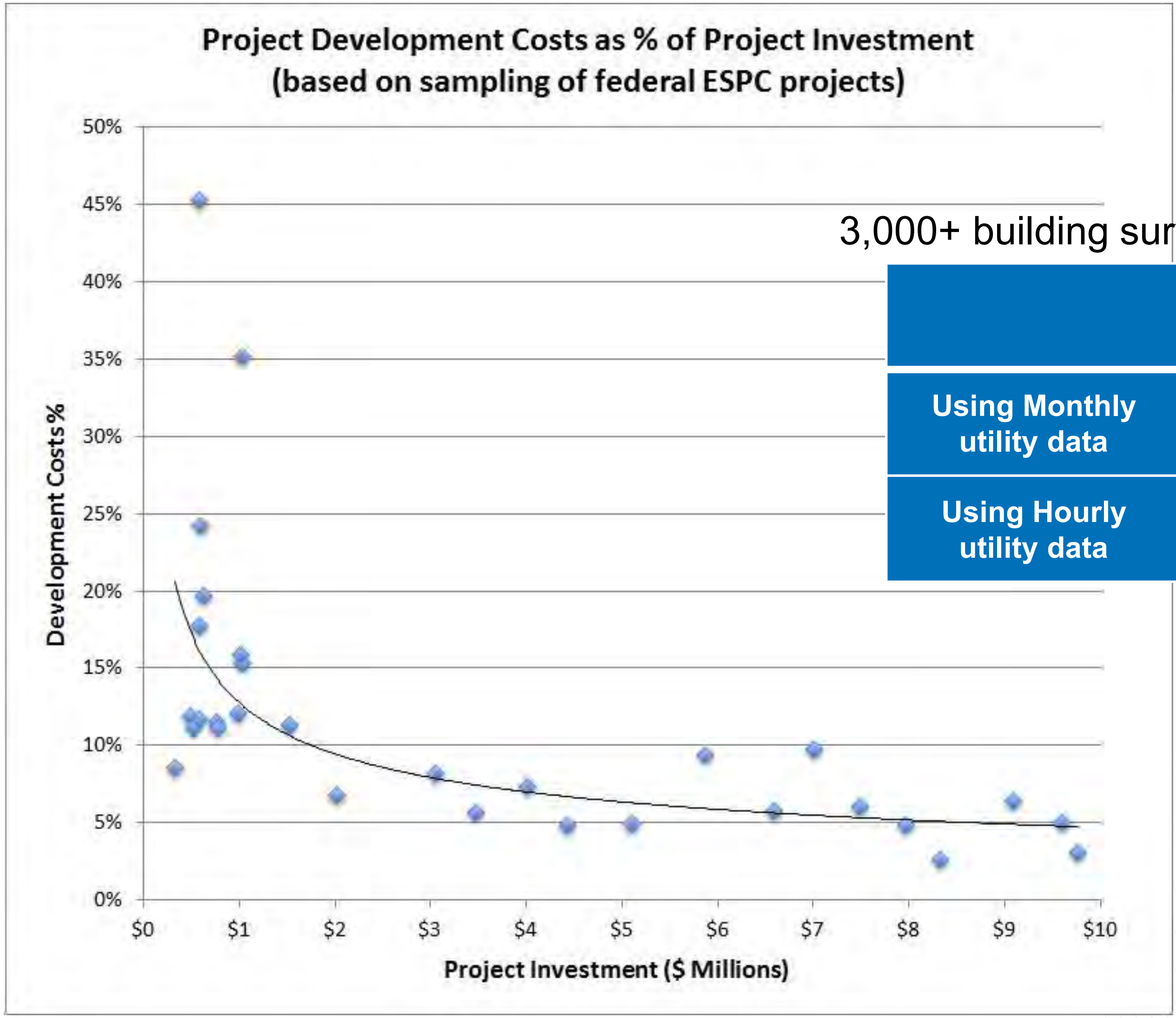
Business limitations for M&V



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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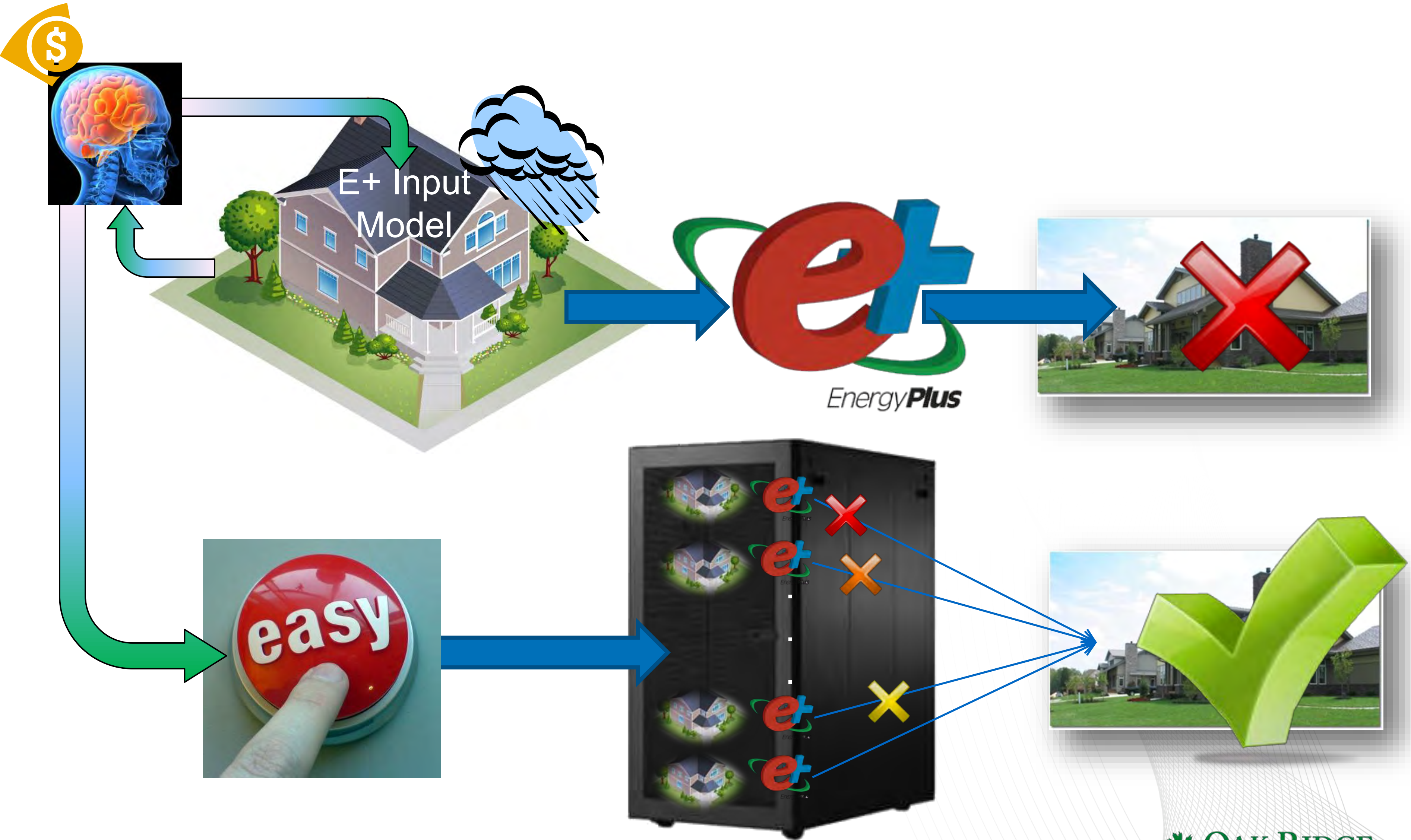
The Autotune Idea
Automatic calibration of software to data



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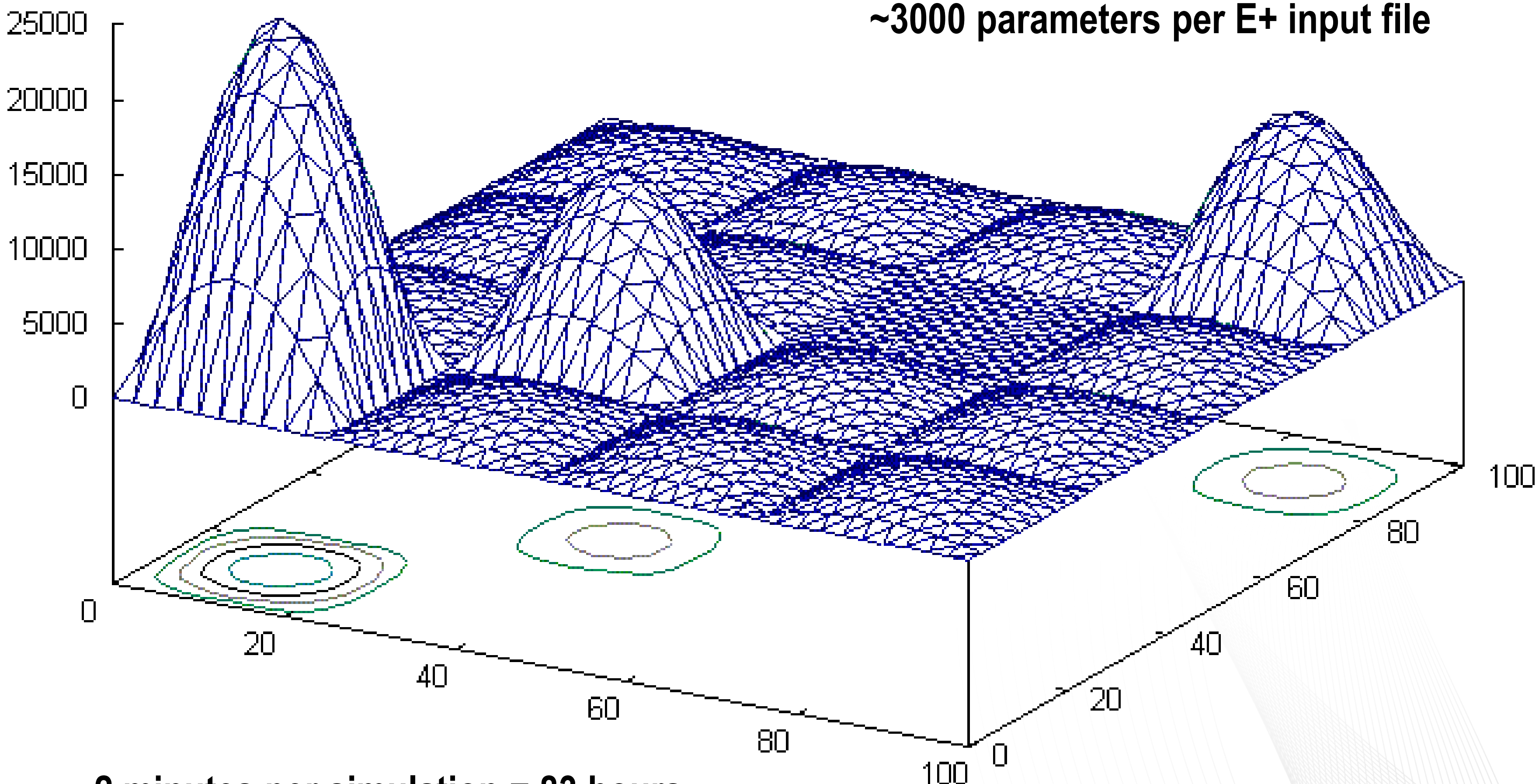
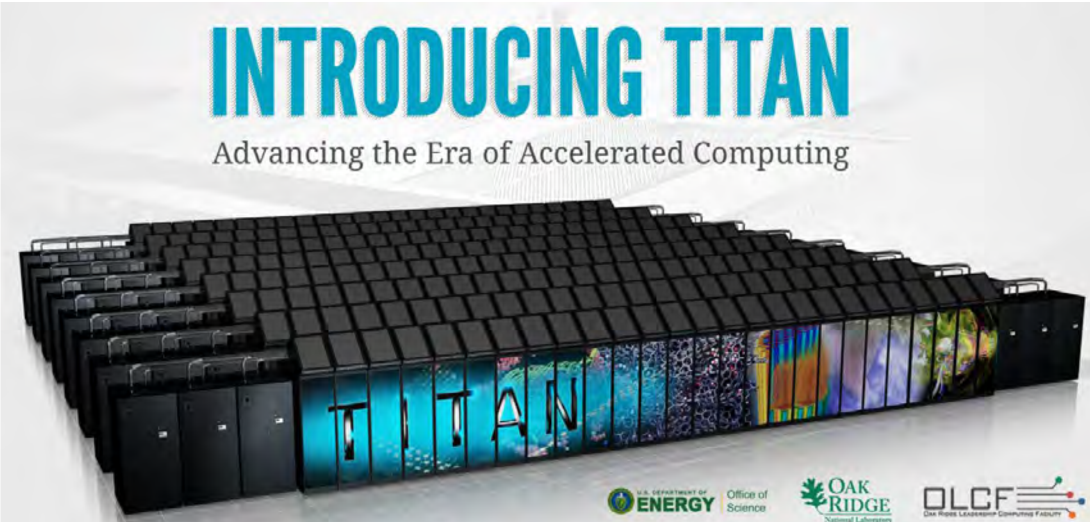
The search problem

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

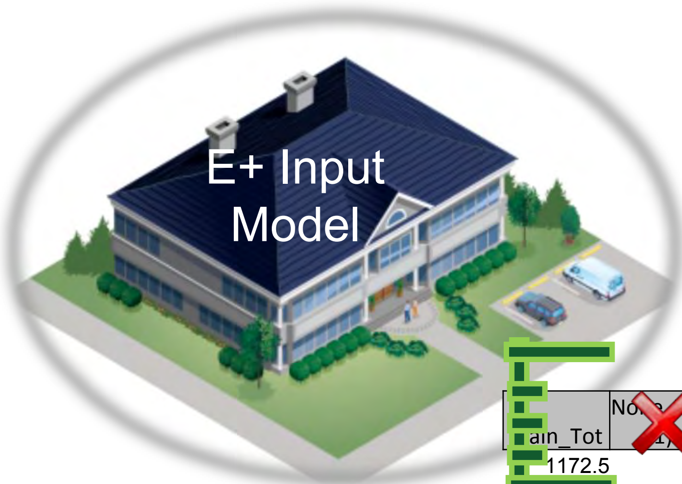
270TB dataset of energy data for buildings

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

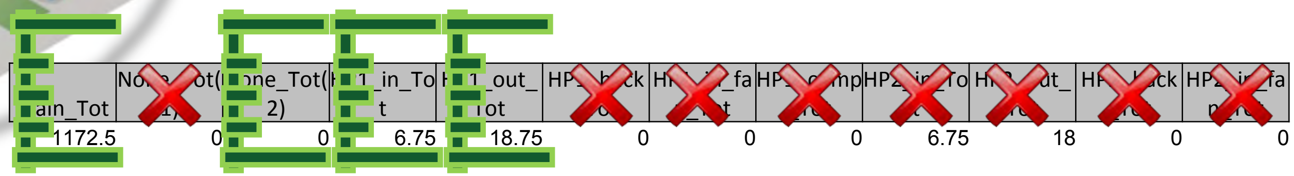


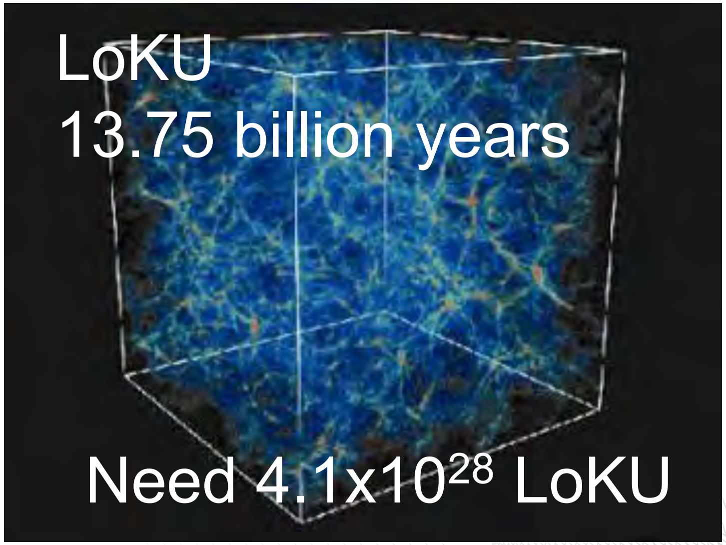
Problems/Opportunities:

Domain experts chose to vary 156

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

E+ parameters





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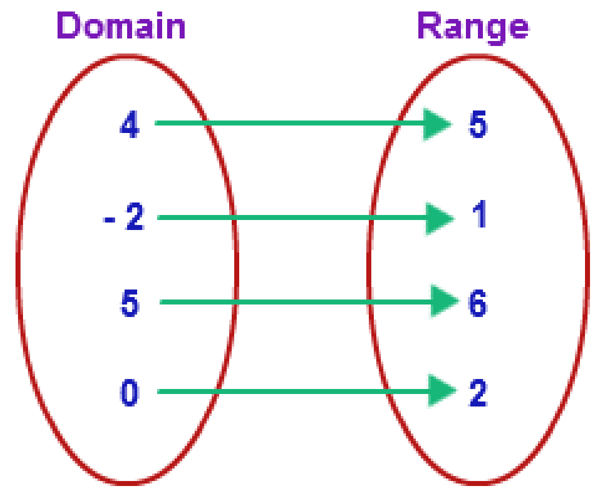
What is artificial intelligence?

- 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

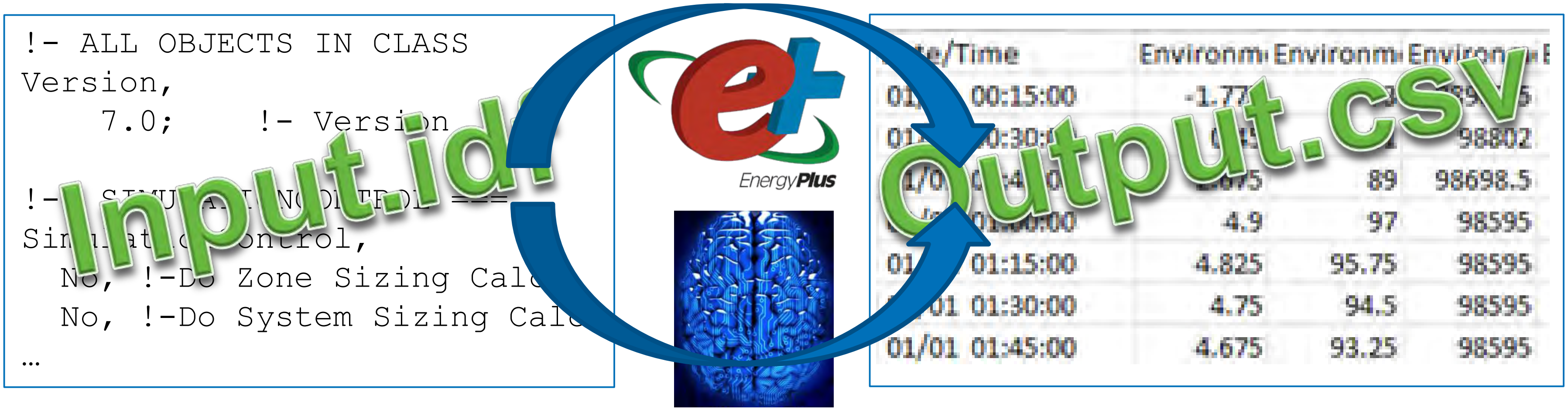
MLSuite: HPC-enabled suite of machine learning algorithms

- 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

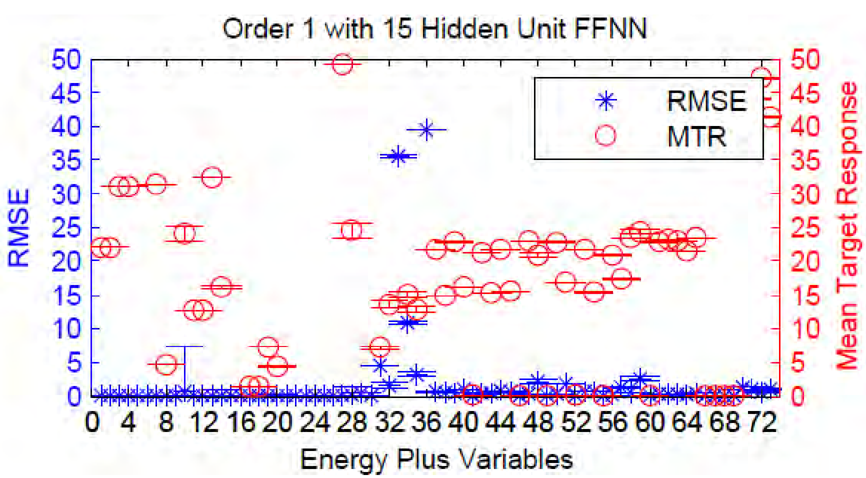
***Acknowledgment:* UTK computer science graduate graduate Richard Edwards, Ph.D. (advisor Dr. Lynne Parker); now Amazon**

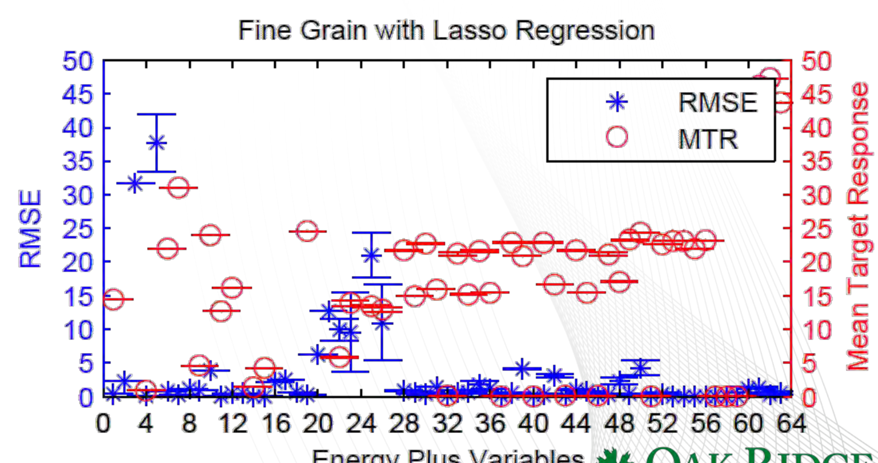
MLSuite example

- EnergyPlus – 2-10 mins for an annual simulation



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

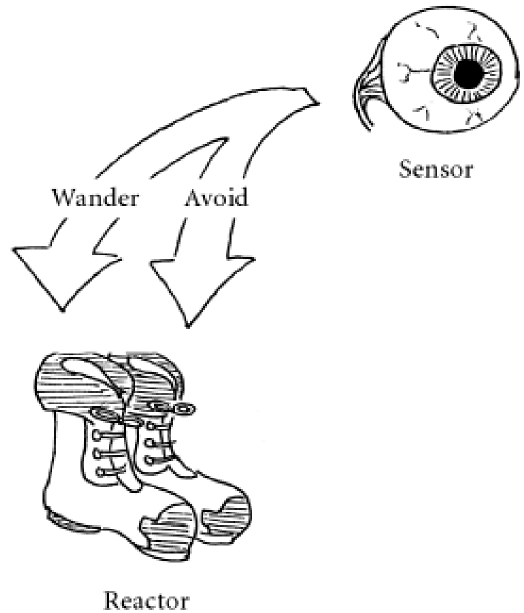




Quote

"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."

Source of Input Data

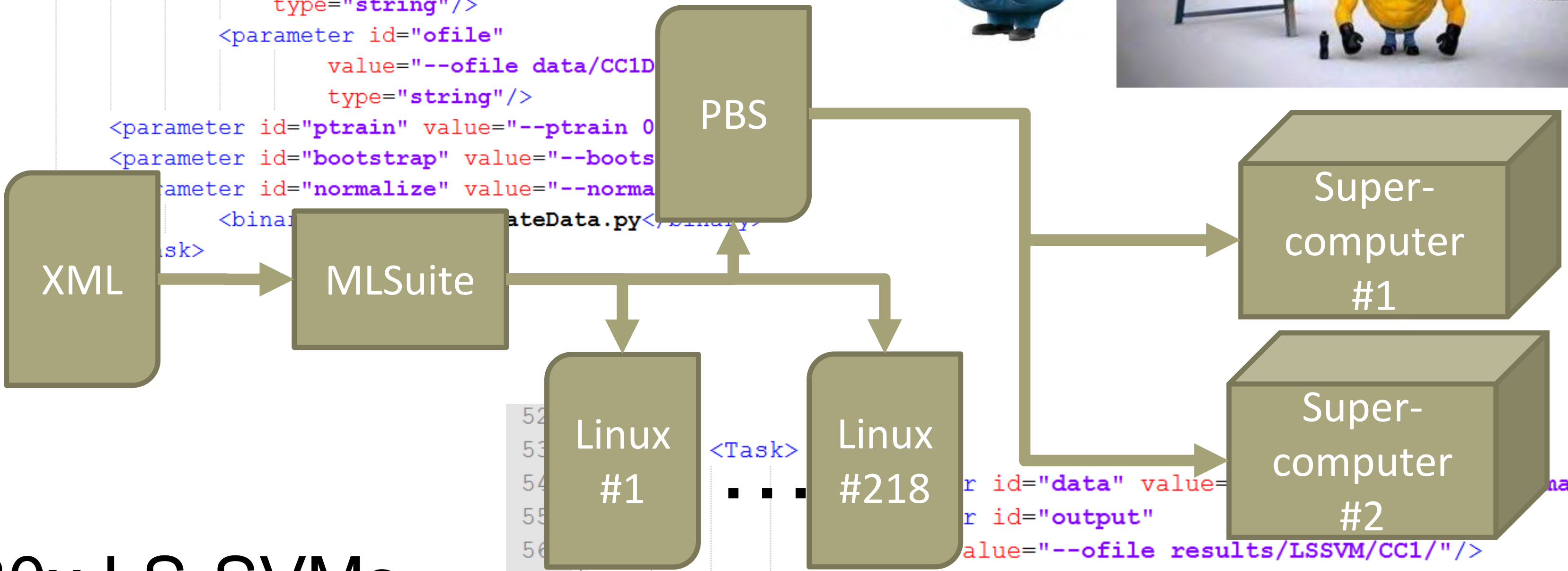
- 3 Campbell Creek homes (TVA, ORNL, EPRI)

- ~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.

MLSuite Architecture

Data Preparation

```
<Job>
    <!-- House 1 Data  -->
    <Task>
        <parameter id="ifile"
            value="--ifile CC1Formated.mat"
            type="string"/>
        <parameter id="ofile"
            value="--ofile data/CC1D
            type="string"/>
    <parameter id="ptrain" value="--ptrain 0
    <parameter id="bootstrap" value="--boots
    ameter id="normalize" value="--norma
        <binar            ateData.py</binary>
    sk>
```



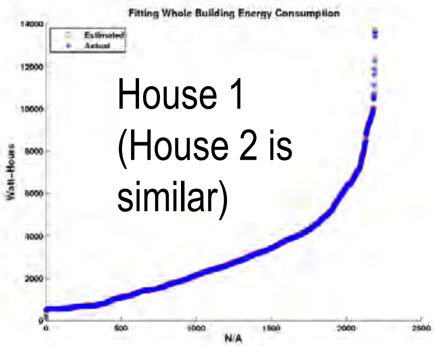
30x LS-SVMs

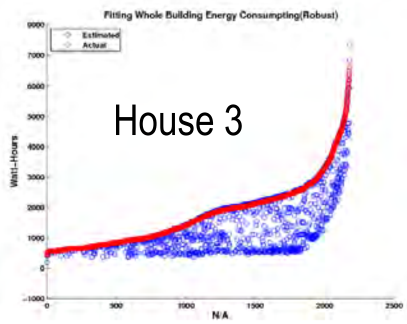
validation folds 1-10
input orders 1-3

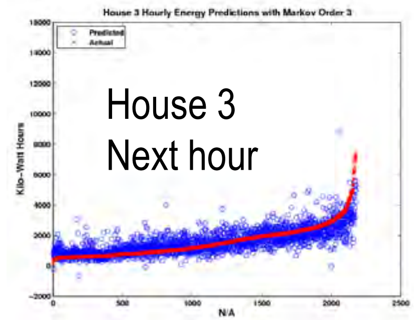
```
    <Task>
        r id="data" value=                    mat"/>
        r id="output"
        alue="--ofile results/LSSVM/CC1/"/>
        <parameter id="fold" value="--fold" type="string"/>
        <parameter id="foldv" value="1" maxvalue="10" step="1"
            type="numeric"/>
        <parameter id="order" value="--order" type="string"/>
        <parameter id="orderv" value="1" maxvalue="3" step="1"
            type="numeric"/>
        <parameter id="learner" value="--learner EvaluateLSSVM"/>
        <binary path="">Launch.py</binary>
    </Task>
</Job>
```

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):

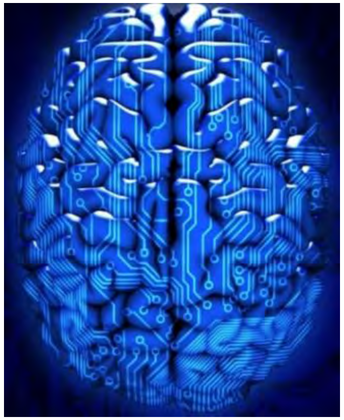
$$MBE = \frac{\frac{1}{N-1}\sum_{i=1}^{N}(y_i - p_i)}{y_{mean}} \times 100$$

	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

Evolutionary computation

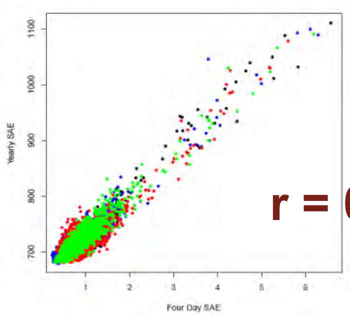
How are offspring produced?

	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

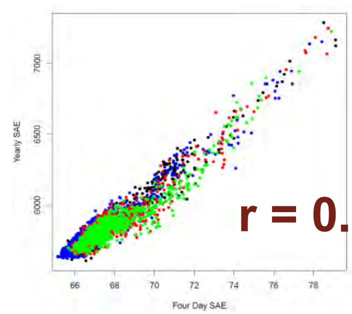
- Average each component
- Add Gaussian noise
- … "AI inside of AI"

Getting more for less

- EnergyPlus is slow
  - Full-year schedule
  - 2 minutes per simulation
- Use abbreviated 4-day schedule instead
  - Jan 1, Apr 1, Aug 1, Nov 1
  - 10 – 20 seconds per simulation



Monthly Electrical Usage



Hourly Electrical Usage

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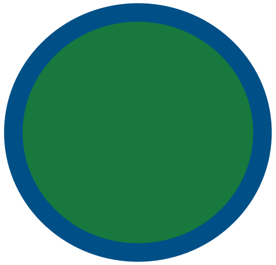
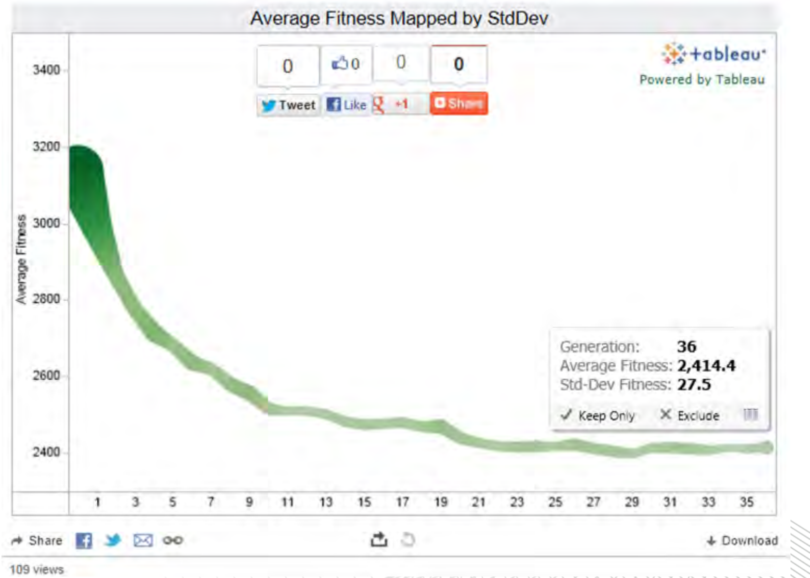
Evolutionary combination



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

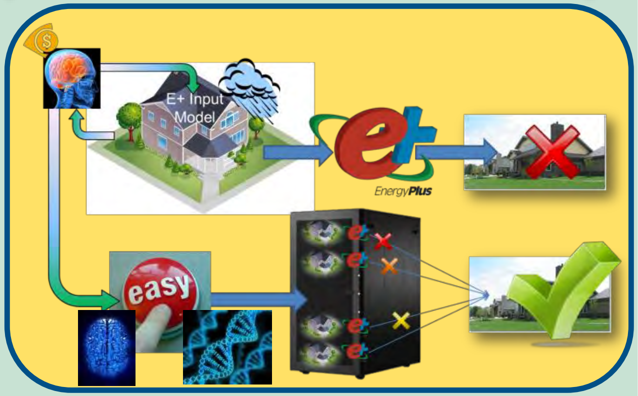
Gordon

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

Kraken

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
Monthly utility data	CVR	15%
	NMBE	5%
Hourly utility data	CVR	30%
	NMBE	10%

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

10+ companies interested

Leveraging HPC resources to calibrate models for optimized building efficiency decisions

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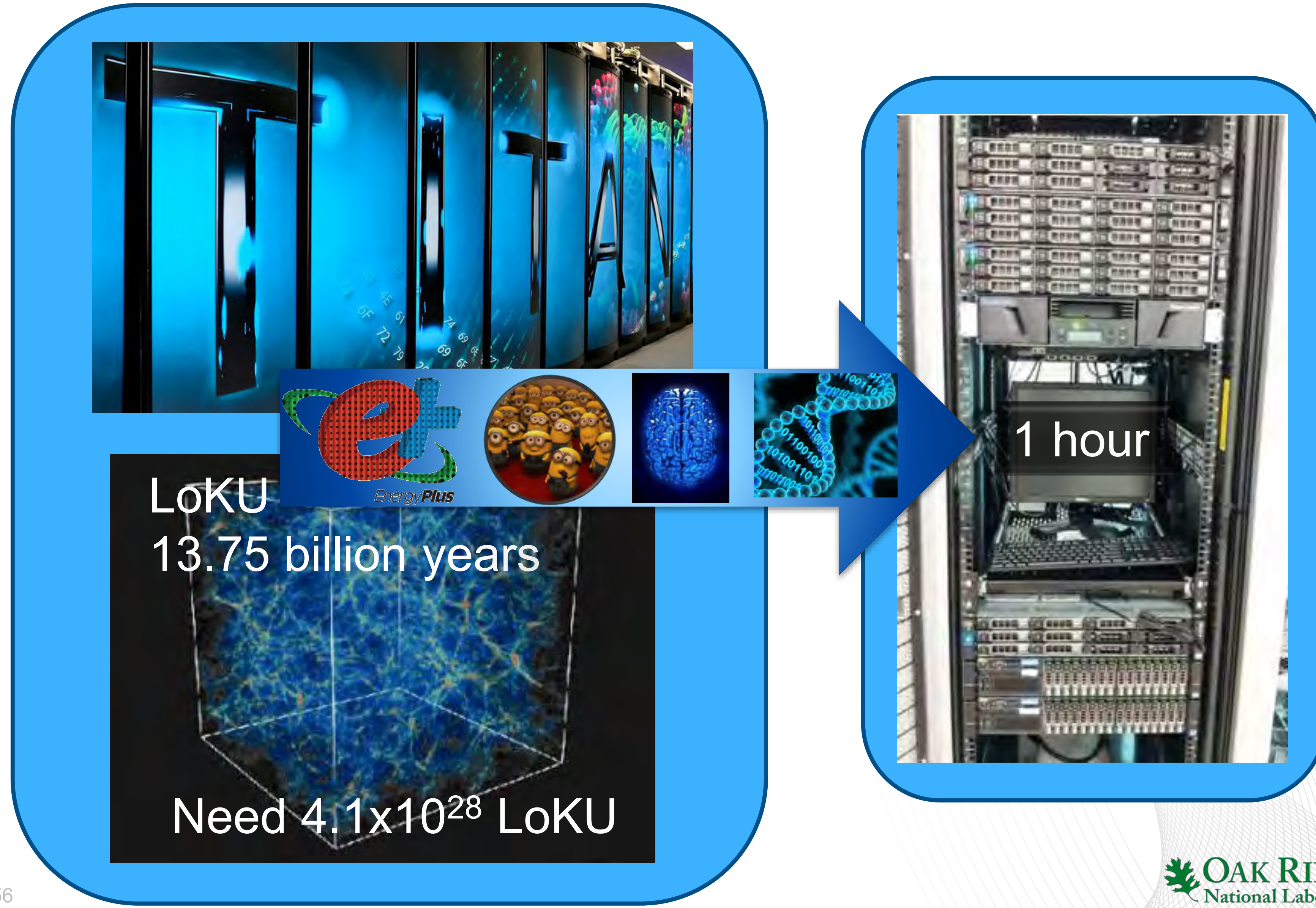
HPC-informed algorithmic reduction… to commodity hardware



That's great, but how can I use it?

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.

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!

Track Progress of Your Model

Check on your model

Enter your tracking # | **Review**

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

IDF Generation

Timestep	1
Run Number	1
Floor Height	3.9624 meters
Plenums	True
Orientation	0.0
Geometry Configuration	Rectangle
Zone Layout	Five Zone
Roof Style	Flat
Wall Type	Steel Frame Non Res
Roof Type	IEAD Non Res
South WWR	0.477
East WWR	0.477
North WWR	0.477
West WWR	0.477
South Window Type	Reference
East Window Type	Reference
North Window Type	Reference
West Window Type	Reference
HVAC Type	VAV
Heating Coil	Gas
Has Reheat	True
Reheat Coil	Electric

Commercial

60+ fields (optional)

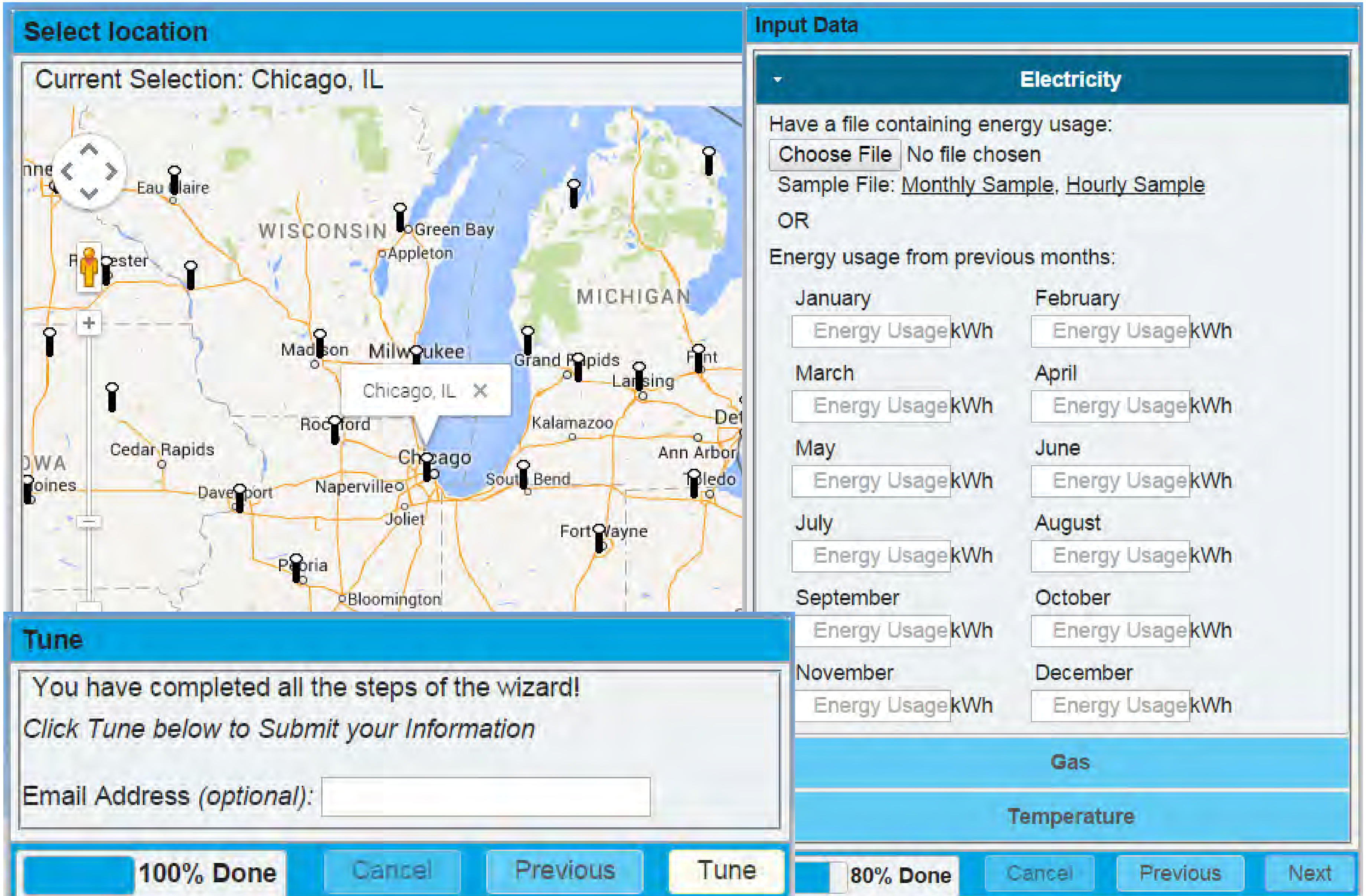
Determine inputs to calibrate

	Restaurant	Hospital	Large Hotel	Large Office	Medium Office	Midrise Apartment	Primary School	Quick Service
#Inputs	49	227	110	85	81	155	166	54
#Groups	49	146	71	45	38	82	113	54

	Secondary School	Small Hotel	Small Office	Stand-alone Retail	Strip Mall	Super Market	Warehouse	TOTAL
#Inputs	231	282	72	59	113	78	47	1809
#Groups	128	136	61	56	89	73	45	1143

	A	B	C	D	E	F	G	H	I	J
1	**Class**	**Object**	**Field**	**Default**	**Minimum**	**Maximum**	**Distribution**	**Type**	**Group**	**Constraint**
2	Lights	Bakery_Lights	Watts per Zone	18.29	12.803	23.777	uniform	float		
3	Lights	Deli_Lights	Watts per Zone	18.29	12.803	23.777	uniform	float		
4	ElectricEquipment	Bakery_MiscPlug_Ec	Design Level	11244	7870.8	14617.2	uniform	float		
5	ElectricEquipment	Deli_MiscPlug_Equi	Design Level	12105	8473.5	15736.5	uniform	float		
6	GasEquipment	Bakery_MiscGas_Eq	Design Level	5622	3935.4	7308.6	uniform	float		
7	GasEquipment	Deli_MiscGas_Equip	Design Level	6053	4237.1	7868.9	uniform	float		
8	Exterior:Lights	Exterior Facade Ligh	Design Level	13577	9503.9	17650.1	uniform	float		
9	ZoneInfiltration:Desig	Bakery_Infiltration	Flow per Exteri	0.000302	0.000211	0.000393	uniform	float	G0001	
10	ZoneInfiltration:Desig	Deli_Infiltration	Flow per Exteri	0.000302	0.000211	0.000393	uniform	float	G0001	
11	Schedule:Compact	CLGSETP_SCH	Field 4	30	21	39	uniform	float	CA1	
12	Schedule:Compact	CLGSETP_SCH	Field 7	30	21	39	uniform	float	CA2	HA2 - CA2 < - 1
13	Schedule:Compact	CLGSETP_SCH	Field 9	24	16.8	31.2	uniform	float	CA3	HA3 - CA3 < - 1
14	Schedule:Compact	CLGSETP_SCH	Field 11	30	21	39	uniform	float	CA4	HA4 - CA4 < - 1
15	Schedule:Compact	HTGSETP_SCH	Field 4	15.6	10.92	20.28	uniform	float	HA1	
16	Schedule:Compact	HTGSETP_SCH	Field 7	15.6	10.92	20.28	uniform	float	HA2	
17	Schedule:Compact	HTGSETP_SCH	Field 9	21	14.7	27.3	uniform	float	HA3	
18	Schedule:Compact	HTGSETP_SCH	Field 11	15.6	10.92	20.28	uniform	float	HA4	

Provide actual data



Autotune returns calibrated model

Tracking Number:4

Downloading Models

The models below represent the best found so far by the Autotune process. The model's error compared to the supplied data is listed beside each model, and they are ordered from lowest to highest error (where the model with the lowest error is highlighted). Please check the box beside any model that you would like to download.

	Model Id	Error
☑	**39**	**0.0002523**
☑	33	0.0002986
☑	41	0.0032654
☑	42	0.0032456

Check All/Uncheck All

Download   Home

```
<Material>
    <Name>
        Metal Siding
    </Name>
    <Roughness>
        Smooth
    </Roughness>
    <Thickness tuneType="float"
            tuneMin="0" tuneMax="0.5"
            tuneDistribution="uniform"
            tuneGroup="A"
            tuneConstraint="A+B&lt;1">
        0.005
    </Thickness>
```

IDF + CSV = XML

Metric	Value
Input error average	24.38
Input error maximum	66.12
Input error minimum	0.09
Input error variance	228.53
CV(RMSE)	
CH4:Facility [kg](Monthly)	9.95
CO2:Facility [kg](Monthly)	15.42
CO:Facility [kg](Monthly)	20.40
Carbon Equivalent:Facility [kg](Monthly)	14.42
Cooling:Electricity [J](Hourly)	1577.96
Electricity:Facility [J](Hourly)	10.48
…	
NMBE	
CH4:Facility [kg](Monthly)	-9.57
CO2:Facility [kg](Monthly)	-14.78
CO:Facility [kg](Monthly)	-19.52
Carbon Equivalent:Facility [kg](Monthly)	-13.83
Cooling:Electricity [J](Hourly)	592.77
Electricity:Facility [J](Hourly)	-9.52
Electricity:Facility [J](Monthly)	-9.52

143+ outputs

Performance and availability

		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%

Results from 24 Autotune calibrations
(3 building types - 8, 34, 79 tuned inputs each)

		ASHRAE G14 Requires	Autotune Results
Monthly utility data	CVR	15%	1.20%
	NMBE	5%	0.35%
Hourly utility data	CVR	30%	3.65%
	NMBE	10%	0.35%

Results from 20,000+ Autotune calibrations
(15 types – 47-282 tuned inputs each)

FY15 project to begin integration of Autotune web service as an OpenStudio application
Free to use. Pay for cloud computing.

Discussion

Oak Ridge National Laboratory
EESD – Martin Keller
ETSD – Johney Green
BTRIC – Patrick Hughes &
Ed Vineyard
WBCI – Melissa Lapsa

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