Autotune Calibration and Uncertainty Quantification

Presented to:
IBPSA-USA Summer Meeting

Joshua New
BTRIC Subprogram Manager
for Software Tools & Models
Oak Ridge National Laboratory
newjr@ornl.gov

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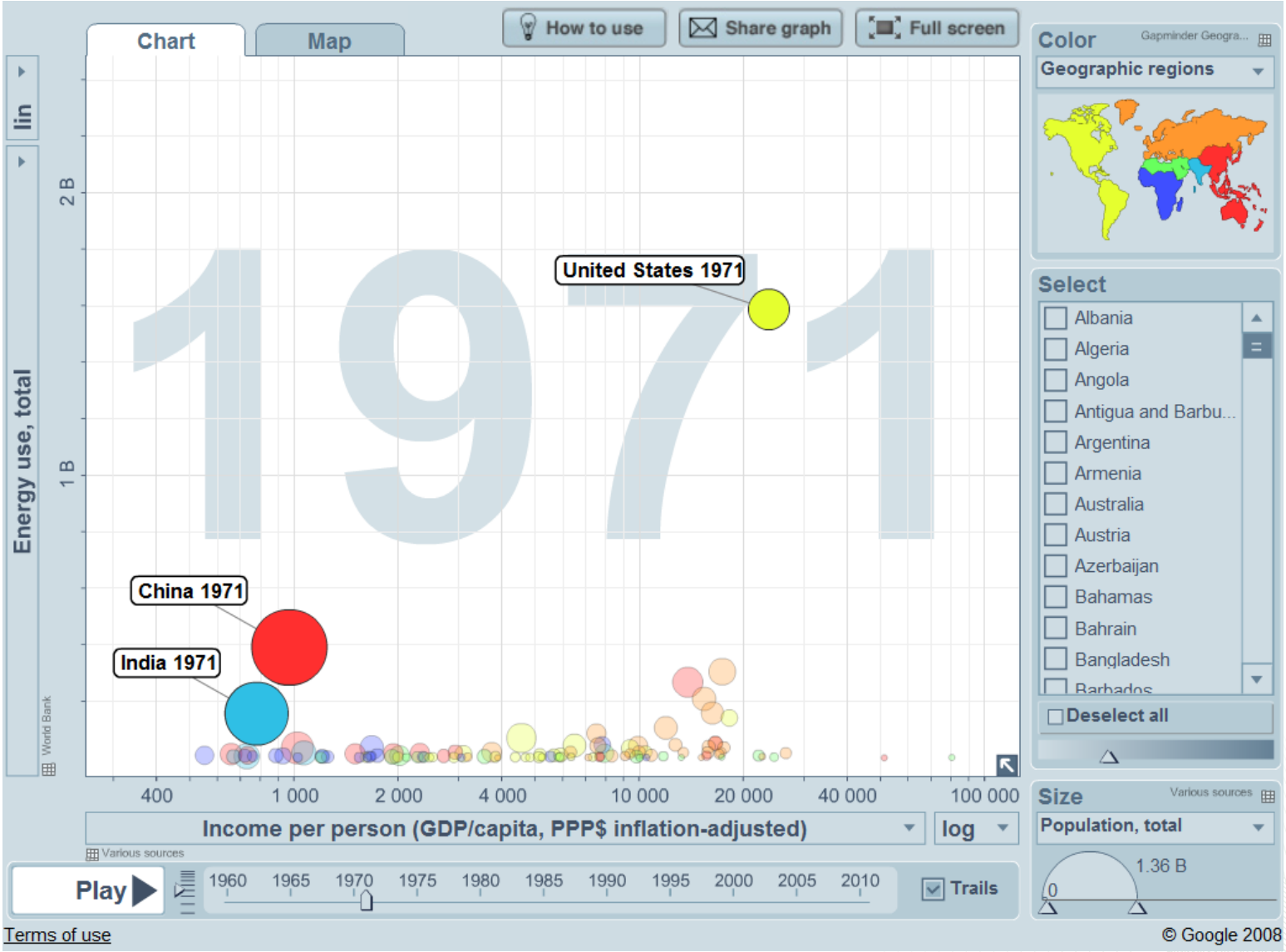
40 Years: Energy and Quality of Life



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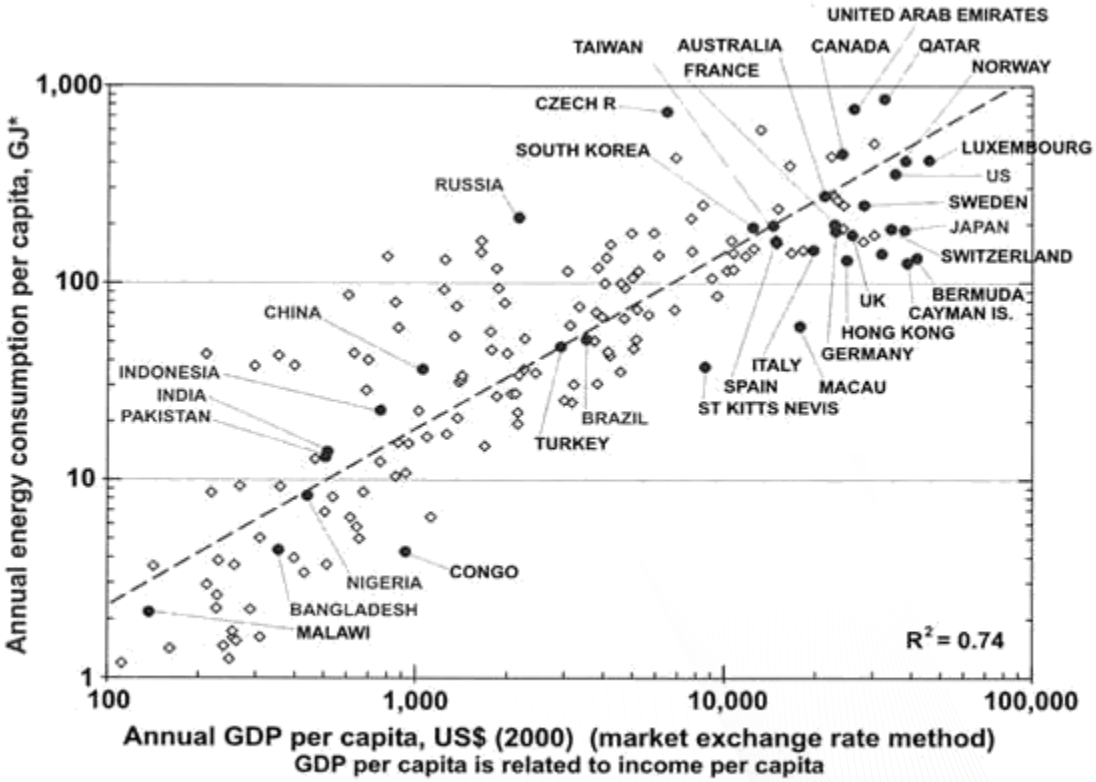
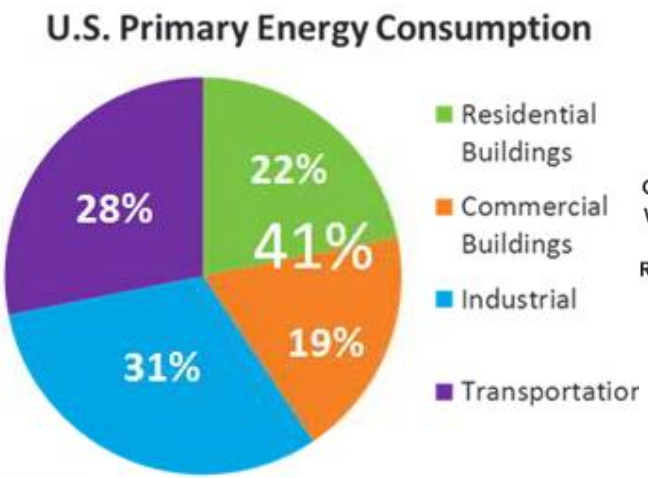
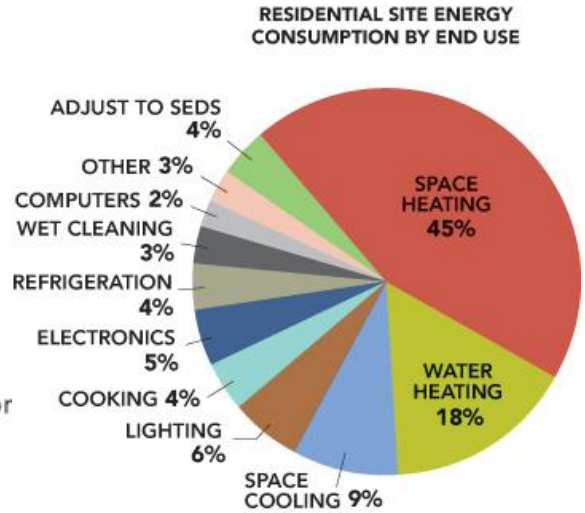
Sustainability is the defining challenge

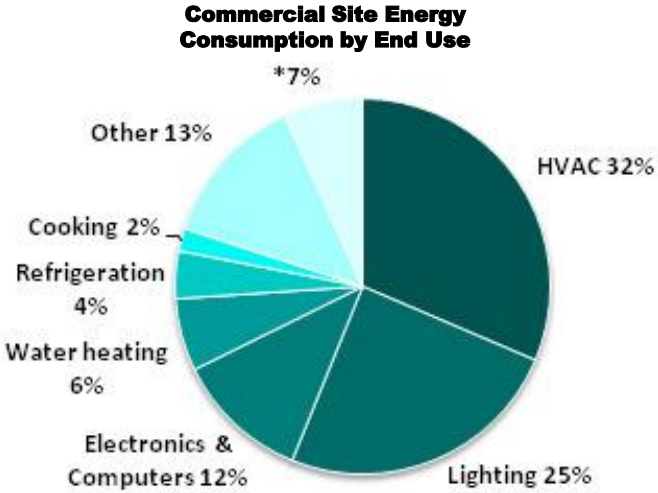
- Buildings in U.S.
  - 41% of primary energy/carbon 73% of electricity, 34% of gas
- Buildings in China
  - 60% of urban building floor space in 2030 has yet to be built
- Buildings in India
  - 67% of all building floor space in 2030 has yet to be built



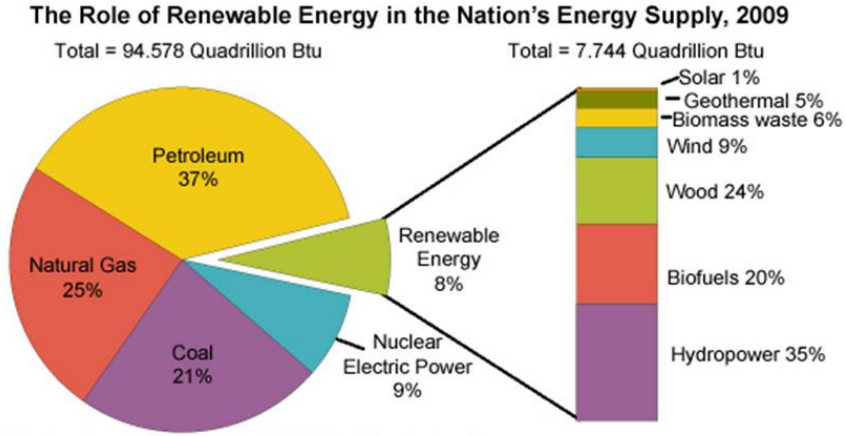
Energy Consumption and Production



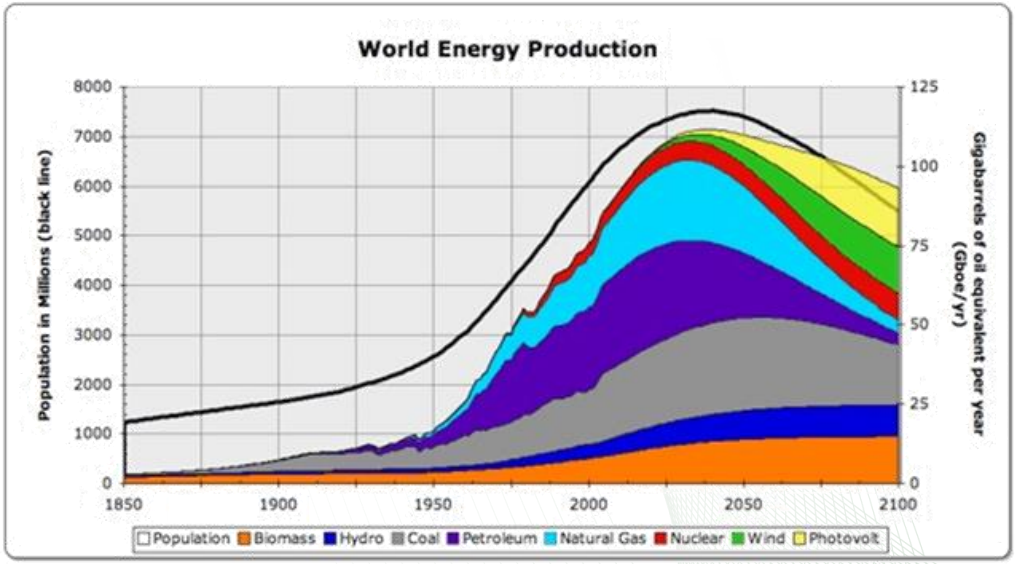




TN 2012 Electric Bill - $1,533



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

- Uncertainty Quantification
- Autotune
- Trinity Tests
- Results

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From Visual Analytics and Simulations To Actualized Energy Savings in the Marketplace

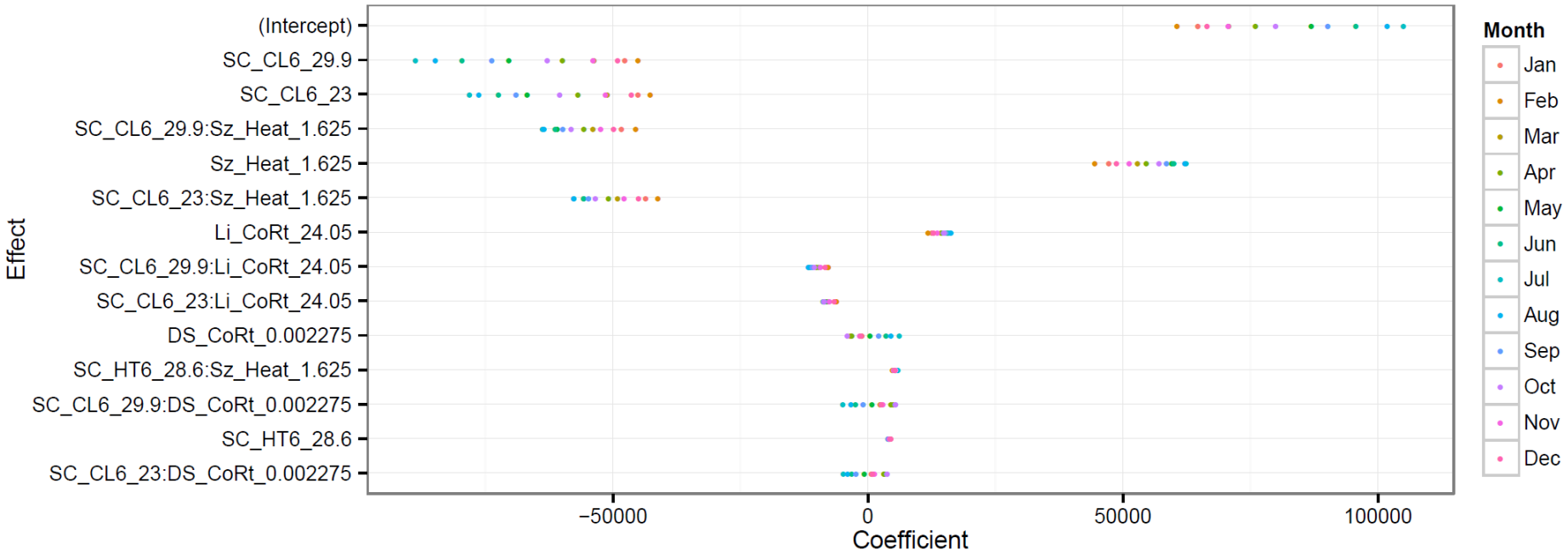
- Titan is the world's #1 fastest buildings energy model simulator
- 500,000+ EnergyPlus building simulations in less than an hour
- 125.1 million U.S. buildings could be simulated in 2 weeks
- 8 million simulations for DOE ref. buildings
- Publicly available resource

20 Inputs Sampled

Class	Name	Short Name	Field	Default	Min	Max
Schedule: Compact	CLGSETP_SCH	SC_CL6	Field 6	23	16.1	29.9
	HTGSETP_SCH	SC_HT4	Field 4	16	11.2	20.8
	HTGSETP_SCH	SC_HT6	Field 6	22	15.4	28.6
Lights	Back_Space_Lights	Li_BaSp	Watts per Zone Floor Area	9	6.3	11.7
	Core_Retail_Lights	Li_CoRt	Watts per Zone Floor Area	18.5	12.95	24.05
	Front_Entry_Lights	Li_FrEn	Watts per Zone Floor Area	12	8.4	15.6
	Front_Retail_Lights	Li_FrRt	Watts per Zone Floor Area	18.5	12.95	24.05
	Point_Of_Sale_Lights	Li_POS	Watts per Zone Floor Area	18.5	12.95	24.05
Electric Equipment	BackSpace_MiscPlug	Eq_BaSp	Watts per Zone Floor Area	8.2	5.74	10.66
	CoreRetail_MiscPlug	Eq_CoRt	Watts per Zone Floor Area	3.3	2.31	4.29
	FrontRetail_MiscPlug	Eq_FrRt	Watts per Zone Floor Area	3.3	2.31	4.29
	PointOfSale_MiscPlug	Eq_POS	Watts per Zone Floor Area	22	15.4	28.6
ZoneInfil: FlowRate	Back_Space_Infil	ZF_BaSp	Flow per Ext Surface Area	0.00033	0.000231	0.000429
	Front_Entry_Infil	ZF_FrEn	Air Changes per Hour	1.1	0.77	1.43
	Front_Entry_Infil	ZF_FrRtA	Constant Term Coefficient	0	0	1
	Front_Retail_Infil	ZF_FrRtC	Flow per Ext Surface Area	0.00033	0.000231	0.000429
	Point_Of_Sale_Infil	ZF_POS	Flow per Ext Surface Area	0.00033	0.000231	0.000429
DsgnSpec: OutdrAir	SZ DSOA Back_Space	DS_BaSp	Outdr Airflow per Area	0.0008	0.00056	0.00104
	SZ DSOA Core_Retail	DS_CoRt	Outdr Airflow per Area	0.00175	0.001225	0.002275
Sizing: Parameters	Sizing:Parameters	Sz_Heat	Heating Sizing Factor	1.25	0.875	1.625

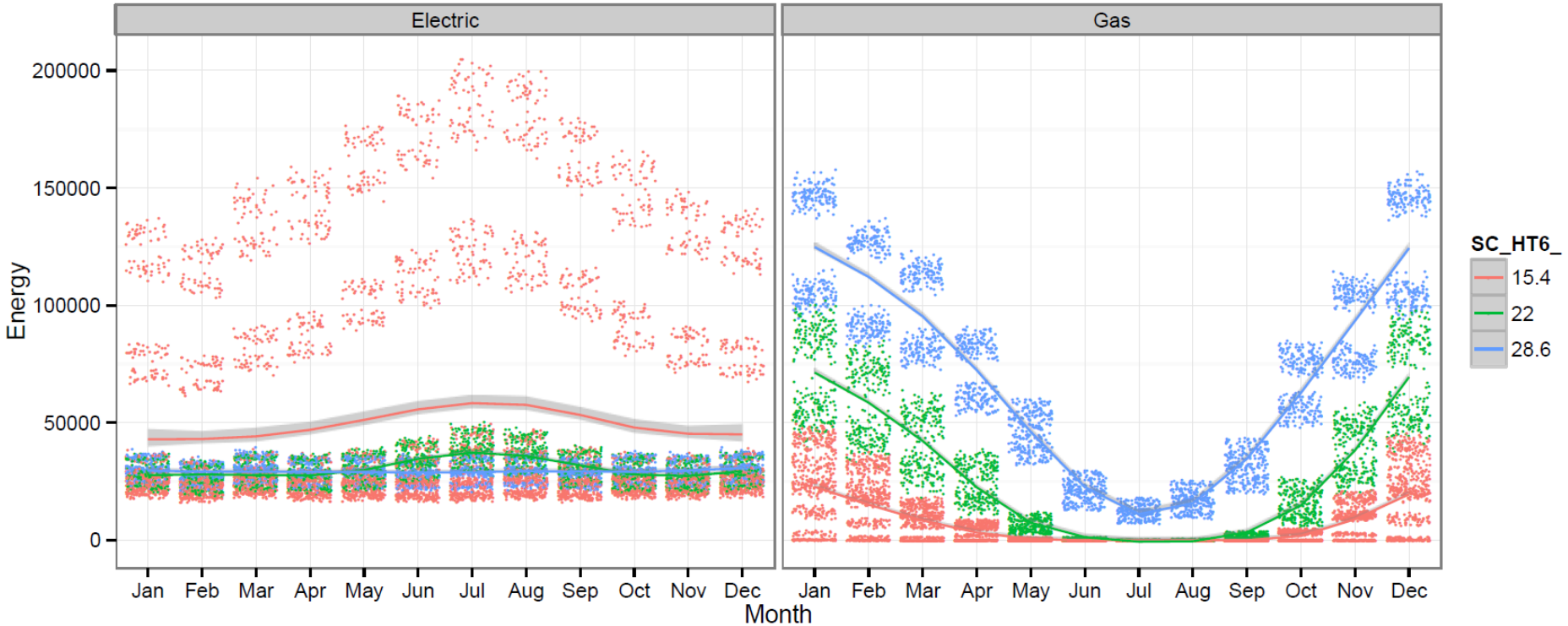
Sensitivity analysis

- 20 factors, all 2-way interactions discoverable with1024 simulations (778 degrees of freedom left for the error term)

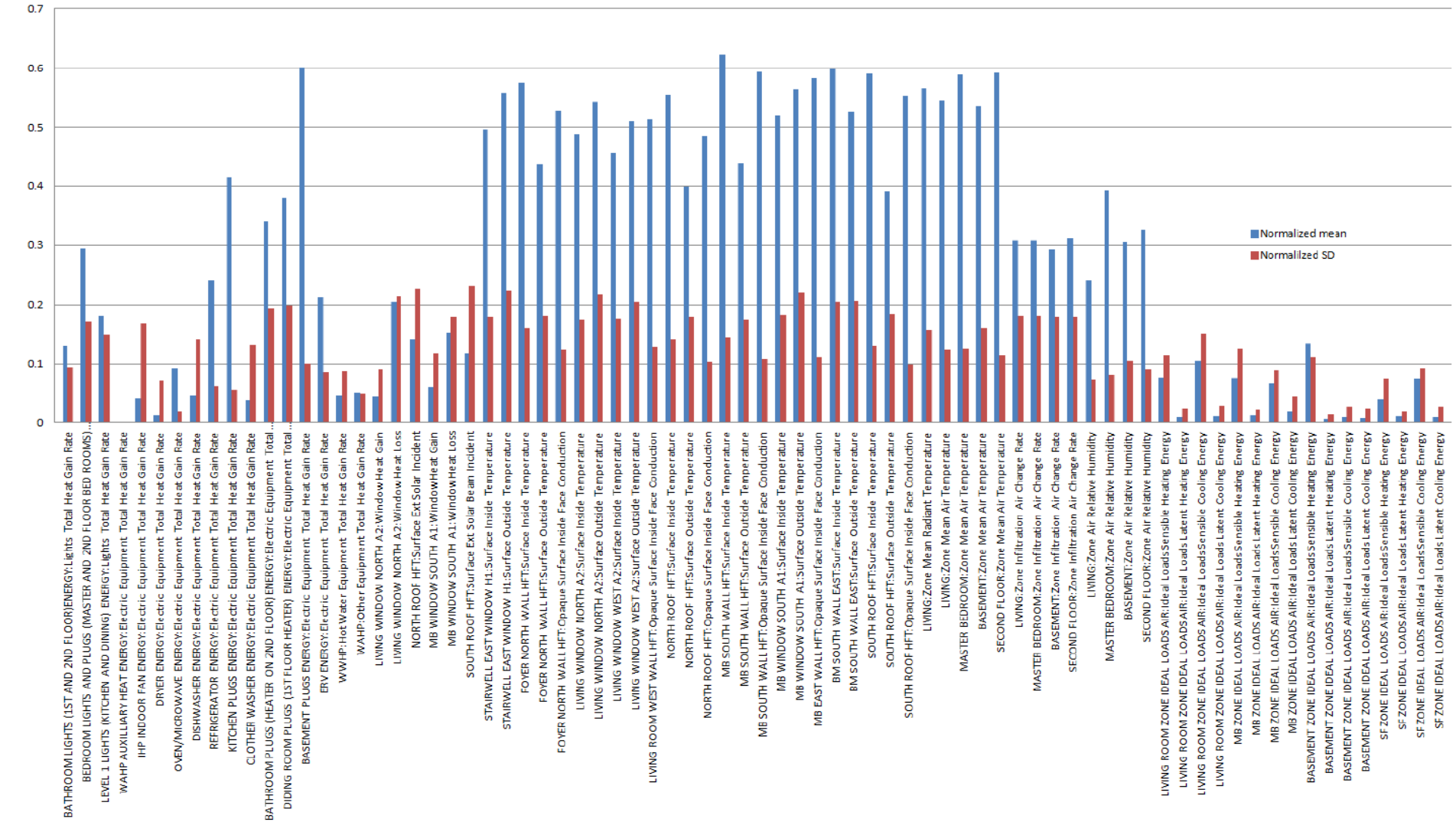


Sesntivity analysis

- Individual effects on any output



156 inputs effect on 96 outputs



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Determine inputs to calibrate

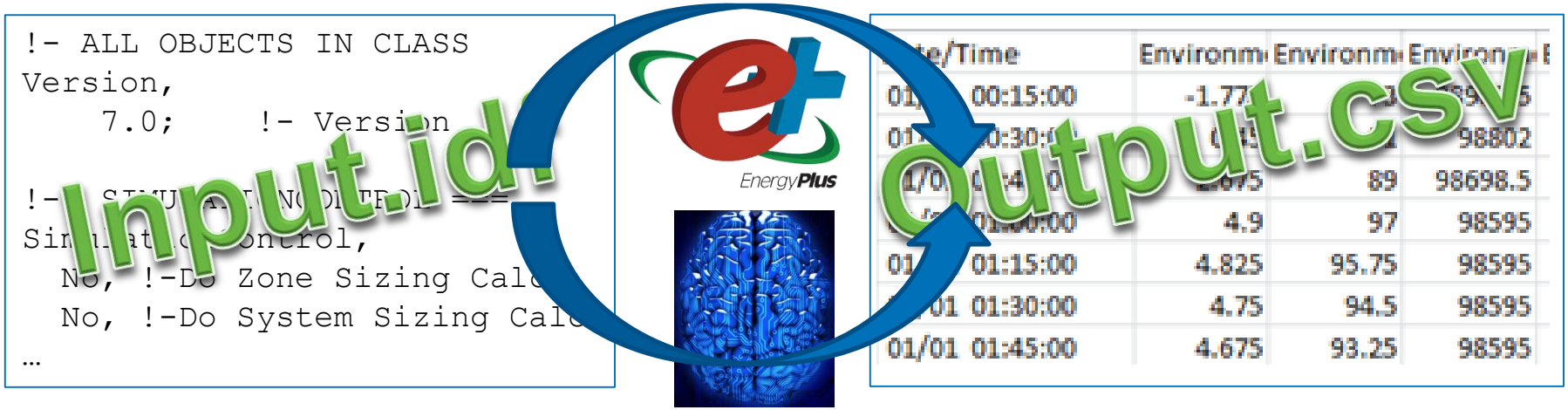
	Restaurant	Hospital	Large Hotel	Large Office	Medium Office	Midrise Apartment	Primary School	Quick Service
#Inputs	49	227	110	85	81	155	166	54
#Groups	49	146	71	45	38	82	113	54

	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

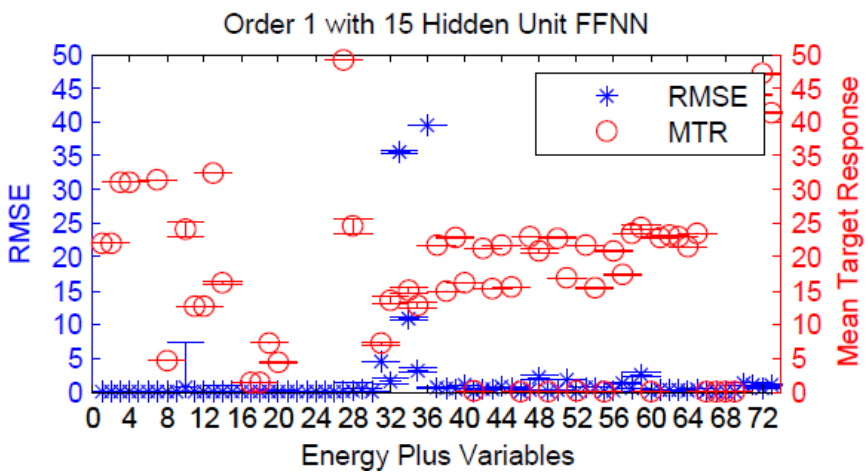
	A	B	C	D	E	F	G	H	I	J
1	Class	Object	Field	Default	Minimum	Maximum	Distribution	Type	Group	Constraint
2	Lights	Bakery_Lights	Watts per Zone	18.29	12.803	23.777	uniform	float		
3	Lights	Deli_Lights	Watts per Zone	18.29	12.803	23.777	uniform	float		
4	ElectricEquipment	Bakery_MiscPlug_Ec	Design Level	11244	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	

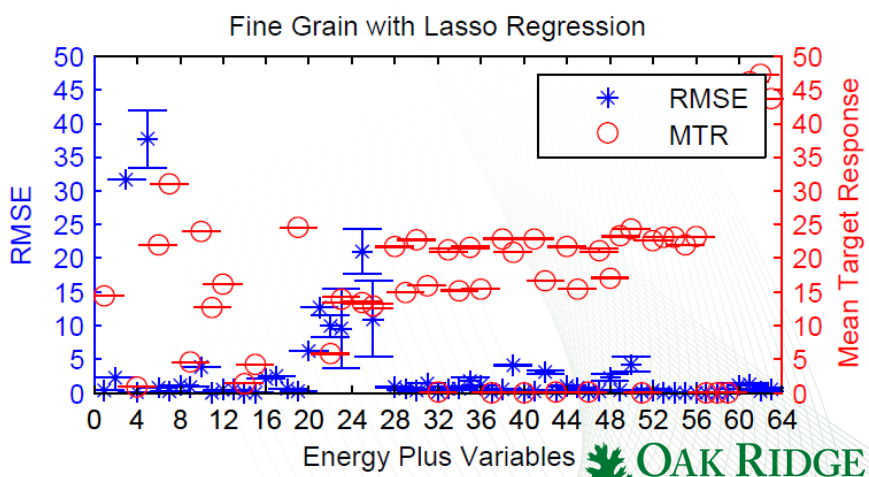
MLSuite example

- 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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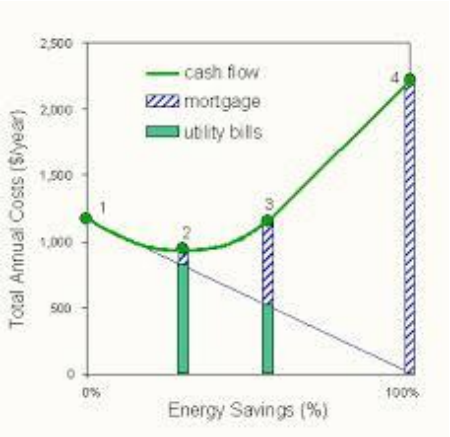
Existing tools for retrofit optimization



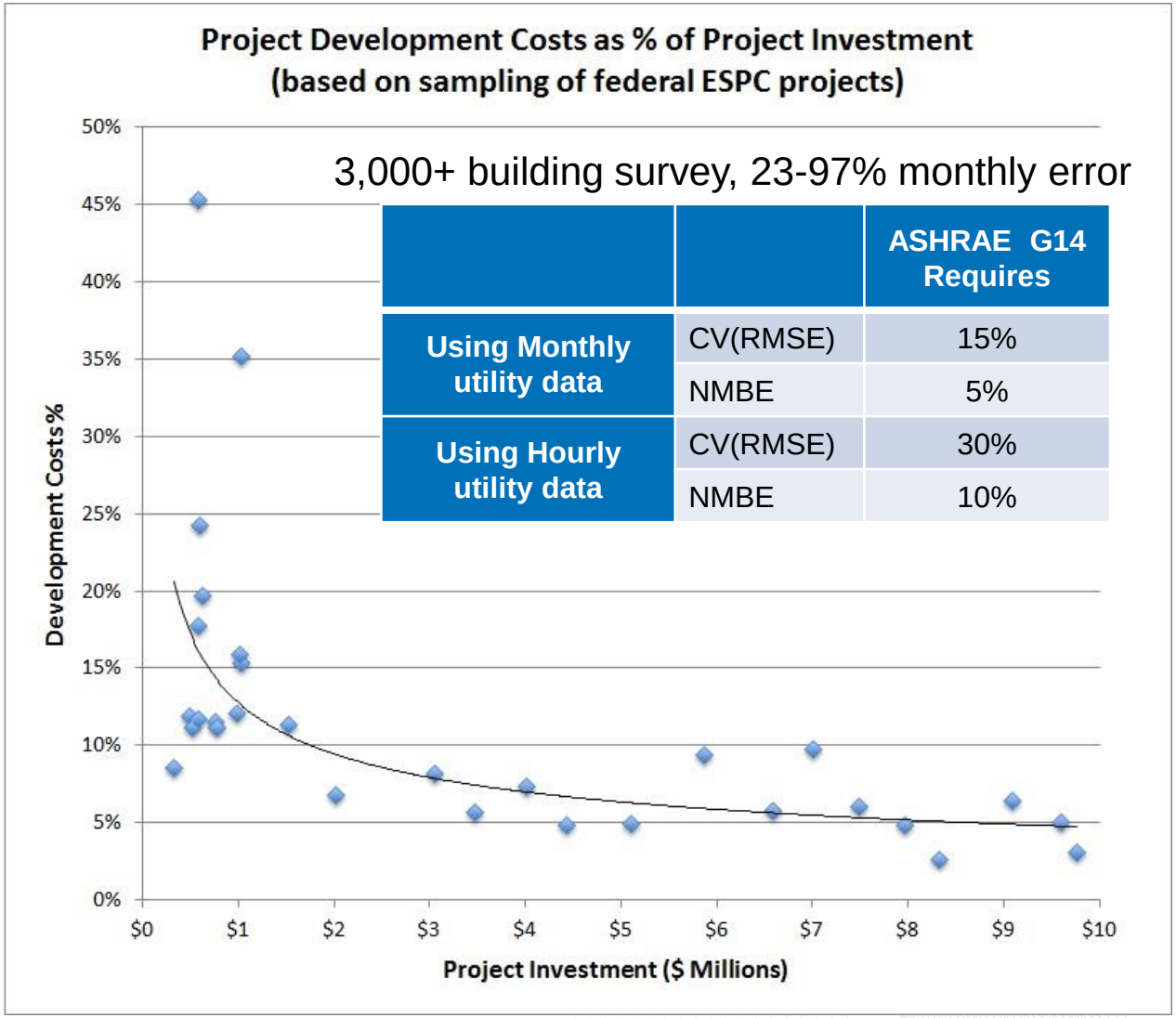
API

OpenStudio

Simulation Engine

DOE–$65M (1995–?)

EnergyPlus



		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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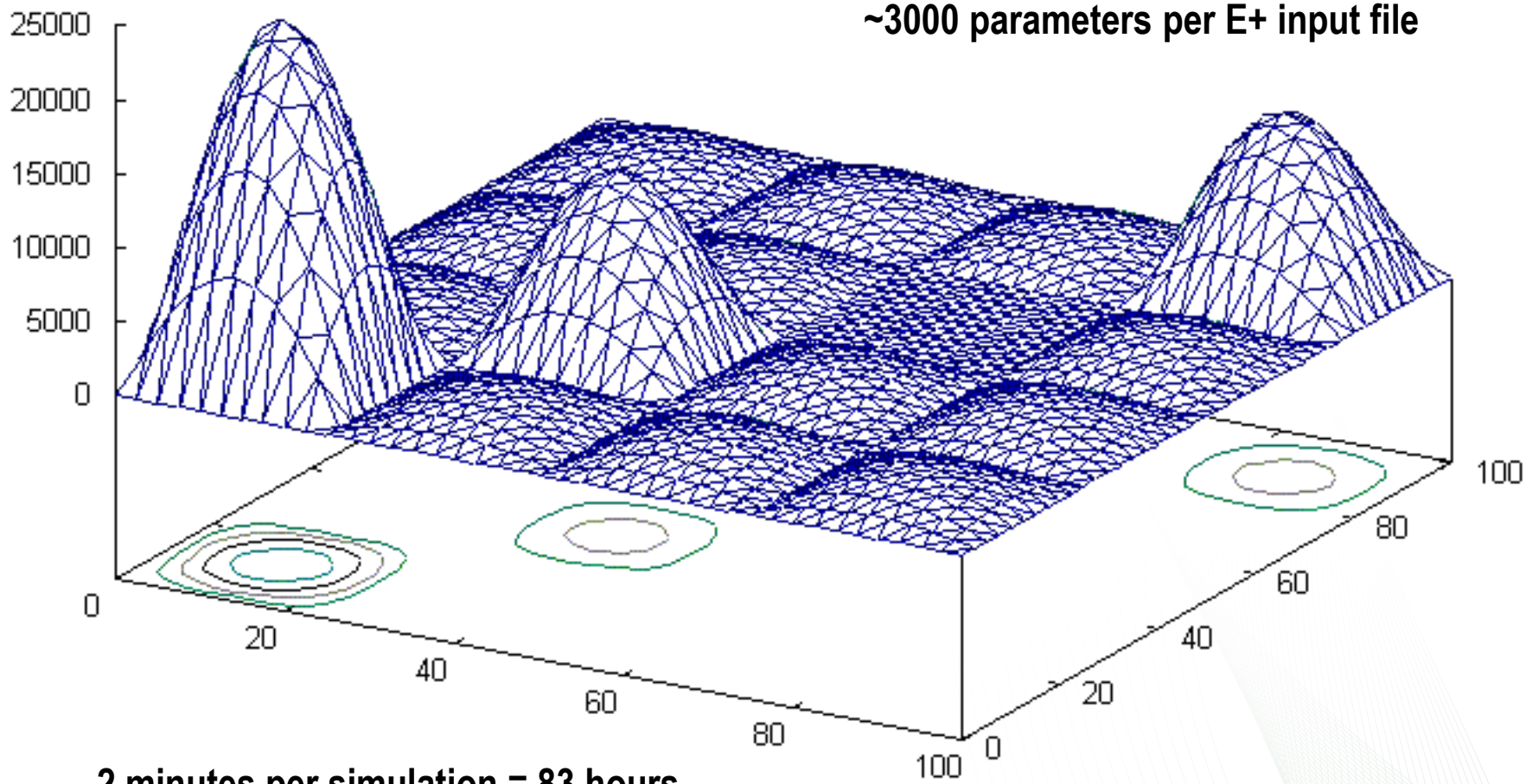
Autotune
Automatic Calibration of Simulation to Data

The search problem

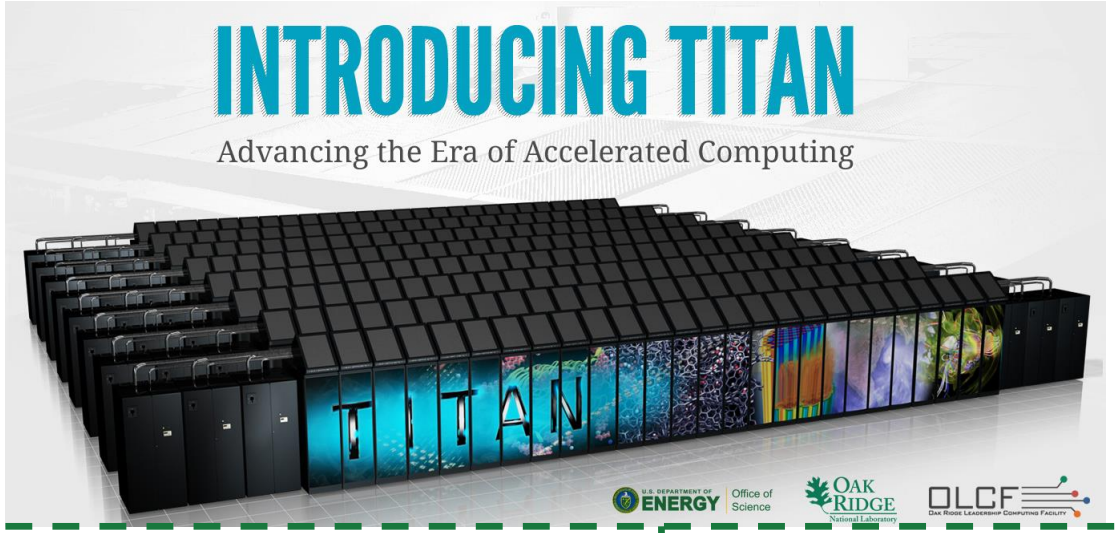
Problem/Opportunity:

~3000 parameters per E+ input file



2 minutes per simulation = 83 hours

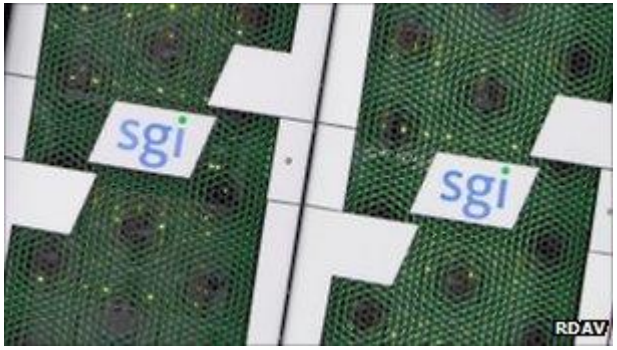
ORNL High Performance Computing Resources



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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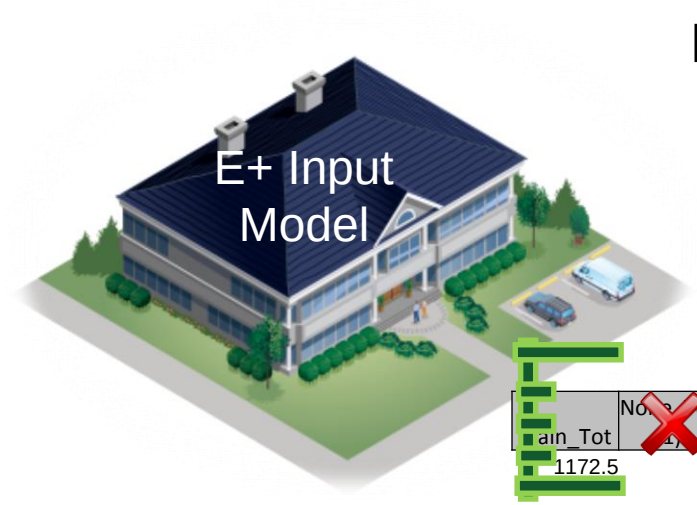
Computational complexity



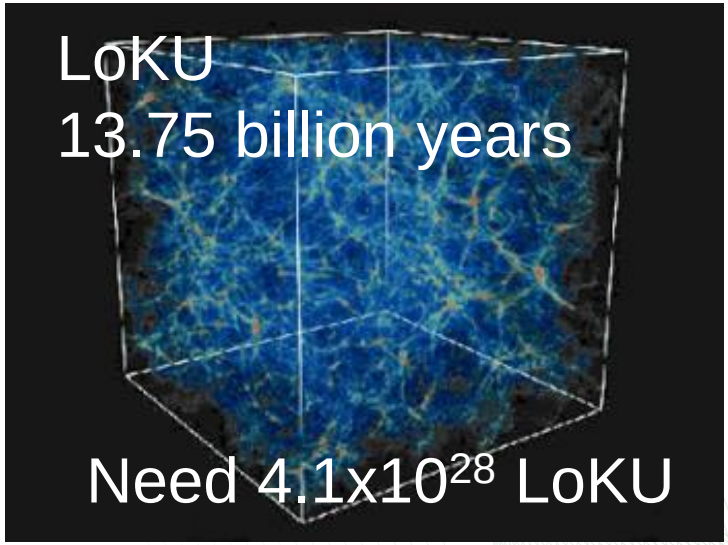
Problems/Opportunities:

Domain experts chose to vary 156

Brute-force = 5×10^{52} simulations

E+ parameters

ain_Tot	No ot(one_Tot(1 2)	1_in_To t	1_out_ Tot	HP k ck	Hi _fa t	HP mp	HP2 in_To	Hi 2 ut_	HP k ck	HP2 in_fa n
1172.5	0	0	6.75	18.75	0	0	0	6.75	18	0	0



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

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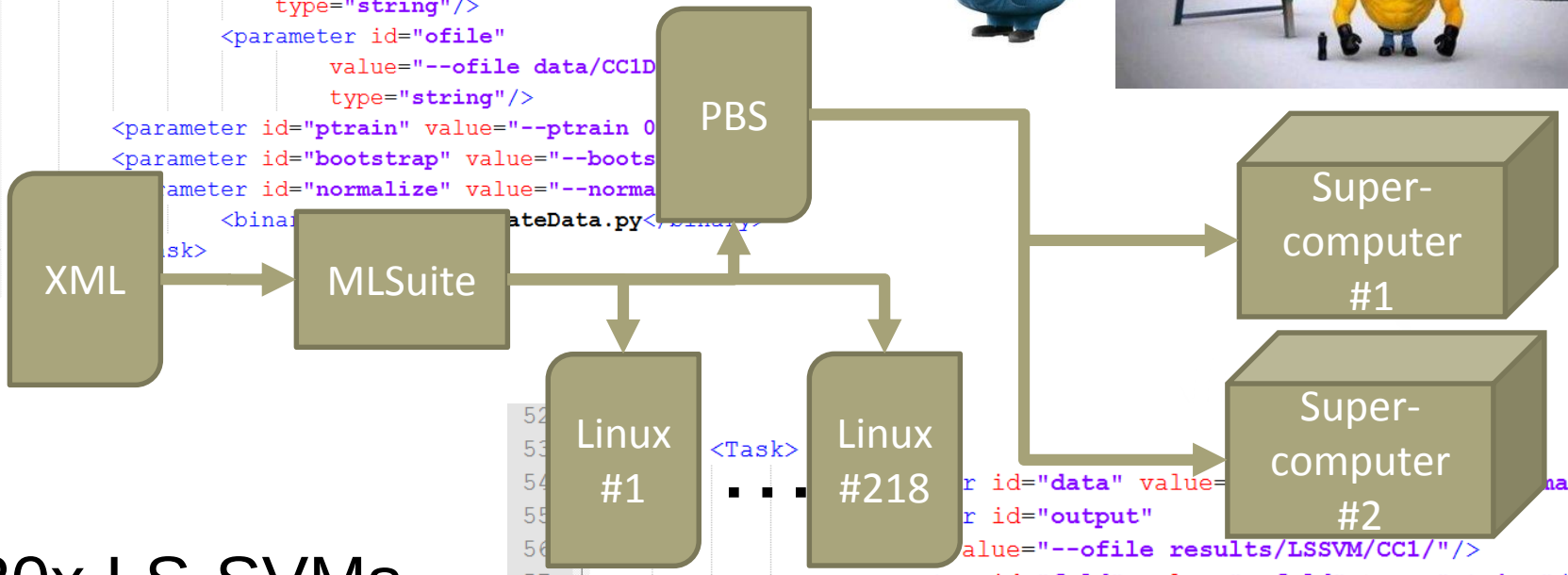
MLSuite Architecture

Data Preparation

```
3  <Job>
4          <!-- House 1 Data  -->
5          <Task>
6                  <parameter id="ifile"
7                      value="--ifile CC1Formated.mat"
8                      type="string"/>
9                  <parameter id="ofile"
10                         value="--ofile data/CC1D
11                         type="string"/>
12         <parameter id="ptrain" value="--ptrain 0
13         <parameter id="bootstrap" value="--boots
14         ameter id="normalize" value="--norma
15                 <binai                ateData.py</binary>
16         sk>
17
```



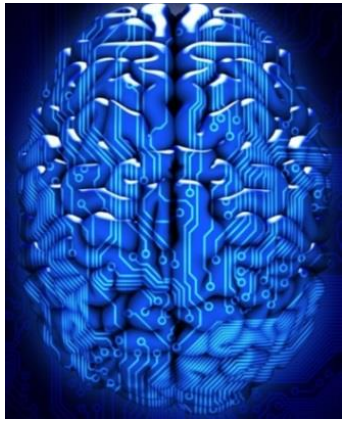

```
52
53         <Task>
54                 r id="data" value=                    mat"/>
55                 r id="output"
56                 alue="--ofile results/LSSVM/CC1/"/>
57                 <parameter id="fold" value="--fold" type="string"/>
58                 <parameter id="foldv" value="1" maxvalue="10" step="1"
59                     type="numeric"/>
60                 <parameter id="order" value="--order" type="string"/>
61                 <parameter id="orderv" value="1" maxvalue="3" step="1"
62                     type="numeric"/>
63                 <parameter id="learner" value="--learner EvaluateLSSVM"/>
64                 <binary path="">Launch.py</binary>
65         </Task>
66 </Job>
```

30x LS-SVMs

validation folds 1-10
input orders 1-3

MLSuite: HPC-enabled Suite of Machine Learning algorithms

- Linear regression
- Feedforward neural network
- Recurrent neural networks
- Support vector machine regression
- Non-linear regression
- Gaussian mixture model with local models
- Self-organizing map
- Kernel Ridge Regression



- Bayesian calibration
- Markov blankets
- Regression tree (using information gain)
- Time modeling with local models
- K-means with local models
- 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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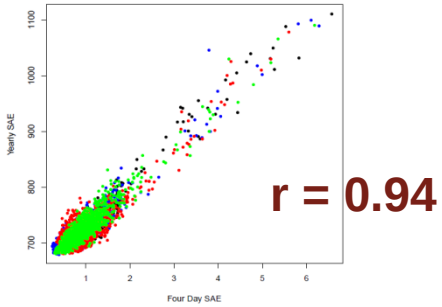
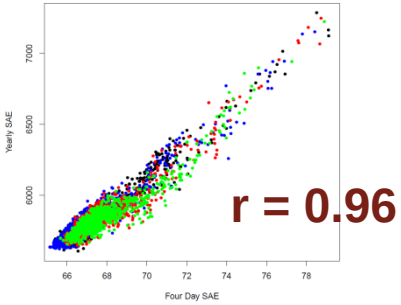
Getting more for less

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

- 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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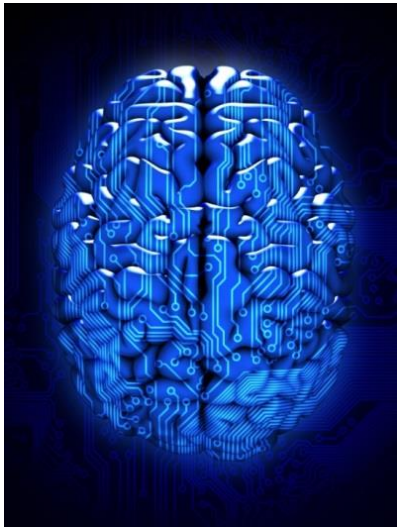
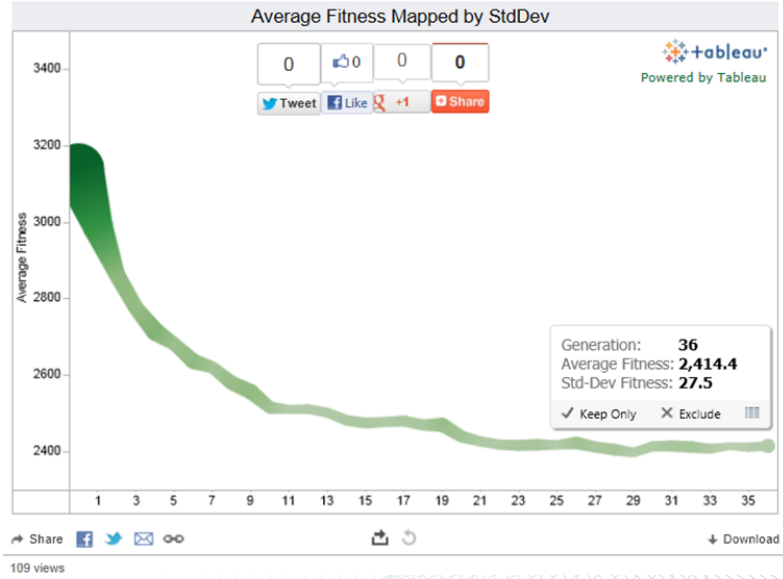
Evolutionary combination

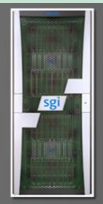
Island Hopping





Autotune Calibrates Building Energy Models

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

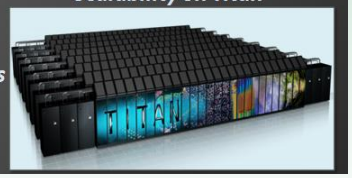
Scalability on Nautilus

Gordon

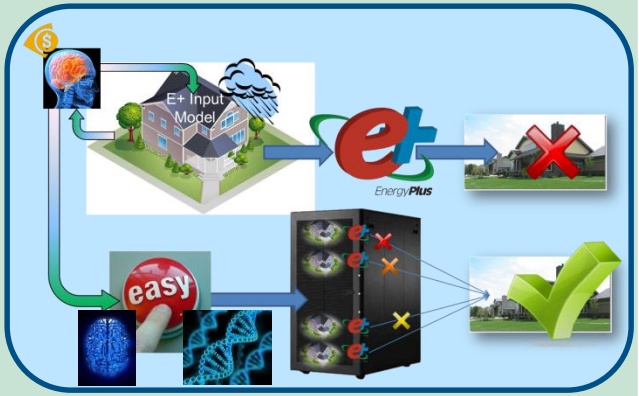
No of Processors	E+ Tasks	Wall-clock Time (mm:ss)
64	256	18:34
128	512	18:22
256	1024	20:30
512	2048	20:43
1024	4096	21:03
2048	8192	21:11
4096	16384	20:00
8192	32768	26:14
16384	65536	26:11
65536	262144	44:52
131072	524288	45TB 68:08

Kraken

Scalability on Titan



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



Features:

- Calibrate any model to data
- EnergyPlus calibrated in 1 hour (web service) or 6 hours (laptop)
- Calibrates to the data you have (monthly utility bills to submetering)

Results

		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 of 24 Autotune calibrations
(3 types, 8, 34, 79 tuned inputs each)

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

20+ organizations interested

Leveraging HPC resources to calibrate models for optimized building efficiency decisions

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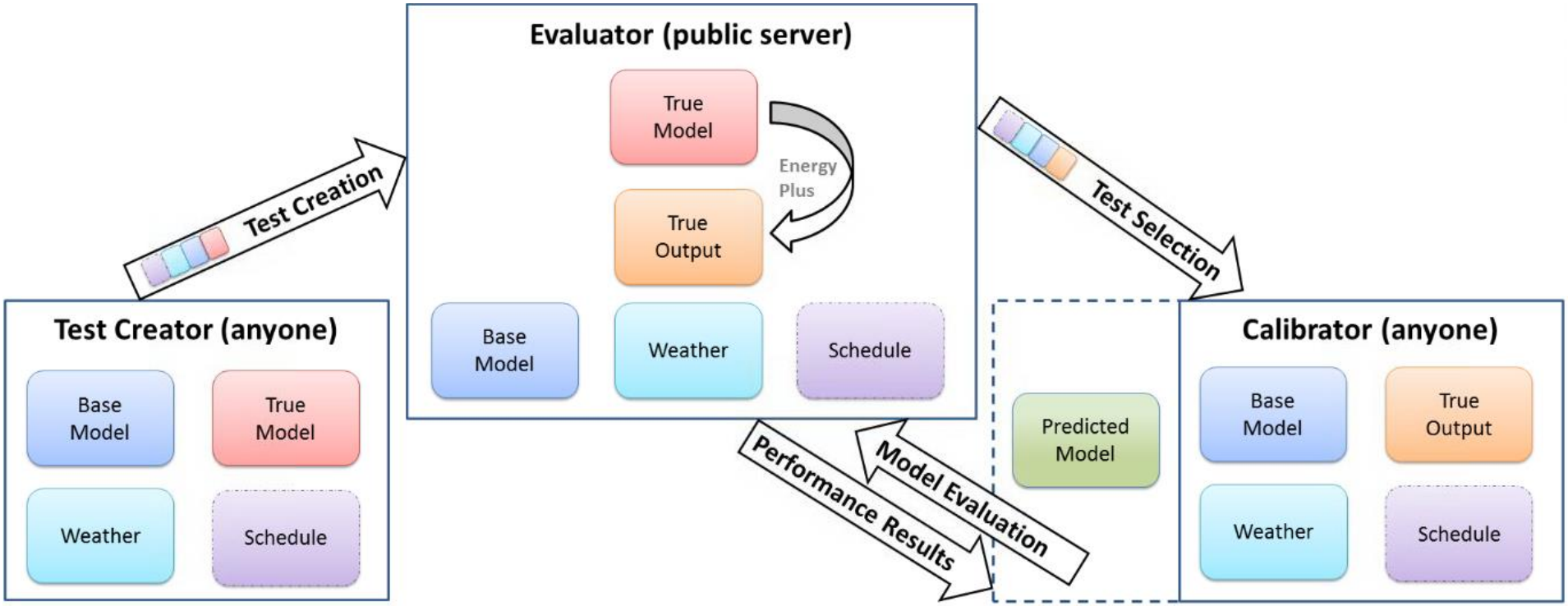
Trinity Test

- System implements BESTEST-EX's "pure calibration"



Trinity Test Availability

Publicly available:
http://bit.ly/trinity_test

- Works only with EnergyPlus 7.0
- Doesn’t capture sensor drift/miscalibration
- Doesn’t capture gap between physics and simulation
- Python script converts IDD to XSD
  - Converts CSV+IDF to XML
  - Converts XML to CSV+IDF

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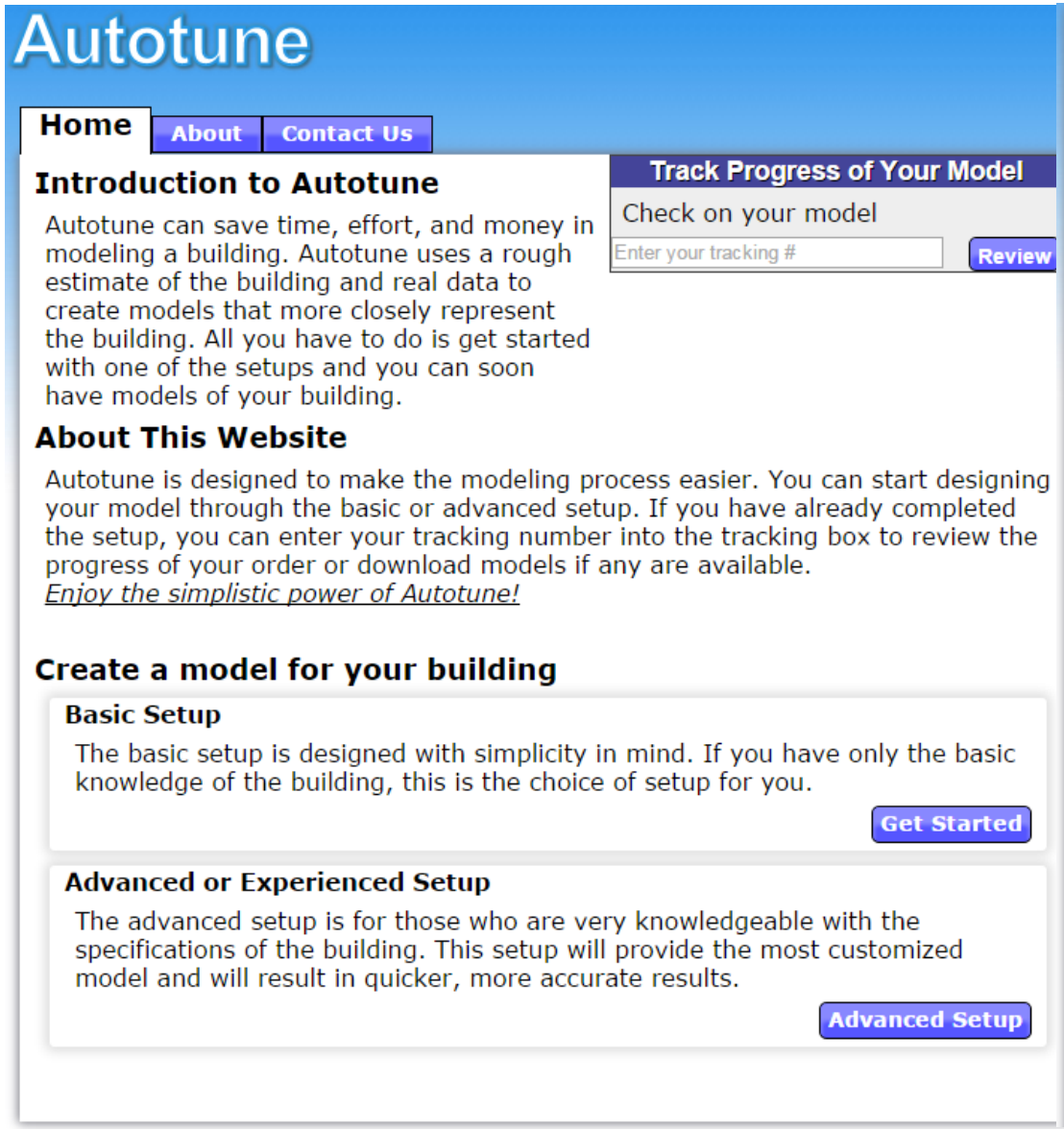
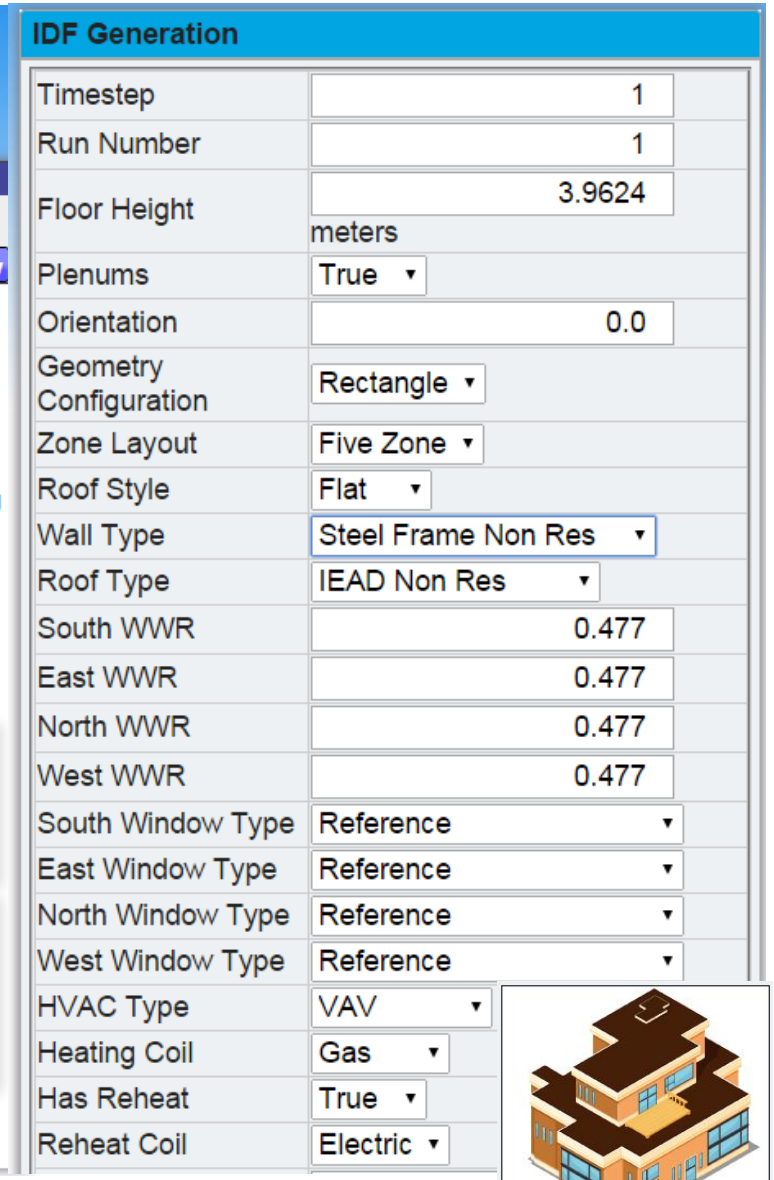
HPC-informed algorithmic reduction… to commodity hardware

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



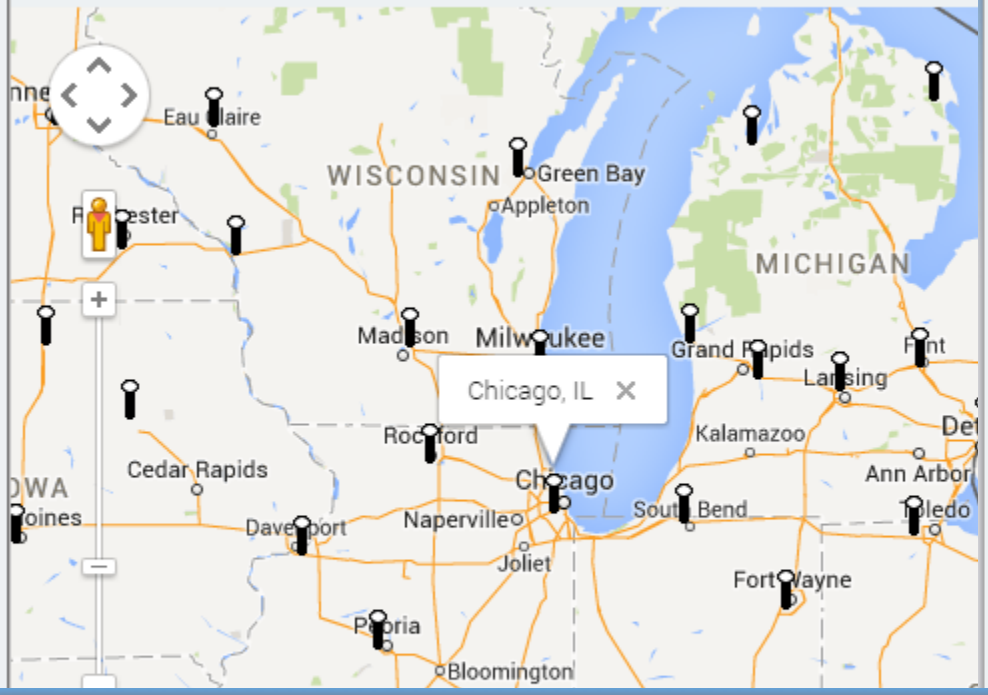


60+ fields (optional)

Provide actual data

Select location

Current Selection: Chicago, IL



Input Data

Electricity

Have a file containing energy usage:

Choose File No file chosen

Sample File: Monthly Sample, Hourly Sample

OR

Energy usage from previous months:

January: Energy Usage kWh	February: Energy Usage kWh
March: Energy Usage kWh	April: Energy Usage kWh
May: Energy Usage kWh	June: Energy Usage kWh
July: Energy Usage kWh	August: Energy Usage kWh
September: Energy Usage kWh	October: Energy Usage kWh
November: Energy Usage kWh	December: Energy Usage kWh

Gas

Temperature

80% Done | Cancel | Previous | Next

Tune

You have completed all the steps of the wizard!

Click Tune below to Submit your Information

Email Address *(optional)*:

100% Done | Cancel | Previous | Tune

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

IDF + CSV = XML

```
1532    <Material>
1533        <Name>
1534            Metal Siding
1535        </Name>
1536        <Roughness>
1537            Smooth
1538        </Roughness>
1539        <Thickness tuneType="float"
1540                   tuneMin="0" tuneMax="0.5"
1541                   tuneDistribution="uniform"
1542                   tuneGroup="A"
1543                   tuneConstraint="A+B&lt;1">
1544            0.005
1545        </Thickness>
```

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

Autotune Performance

		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)

Input-side Error

Hourly – 8%
Monthly – 15%

Autotune Availability

BAD NEWS

FY15 project to integrate
Autotune with OpenStudio
for cloud-based calibration
is on hold indefinitely

GOOD NEWS

Autotune has been open-sourced
and is freely available at
https://github.com/ORNL-BTRIC/Autotune

Backend – does all the work
Service – web service API
Frontend – website

Discussion

Oak Ridge National Laboratory

Joshua New, Ph.D.
newjr@ornl.gov